TYLER BRANCH WATERSHED

PHASE 2
STREAM GEOMORPHIC ASSESSMENT

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1.0 EXECUTIVE SUMMARY

In May, 2008 the Northwest Regional Planning Commission (NRPC) engaged Redstart Forestry and Consulting to conduct Phase 2 geomorphic assessments on twenty stream reaches (reaches are portions of the stream with similar characteristics in terms of channel geometry, valley, and floodplain settings) within portions of the Tyler Branch watershed in Franklin County, VT. The Tyler Branch is a tributary of the Missisquoi River, and this assessment is a part of larger efforts to enhance the health and vitality of Vermont streams and rivers and the communities they support, including efforts by international, federal, state, local and individual partners to improve the water quality within Missisquoi Bay and Lake Champlain.

The 2008 Tyler Branch Phase 2 assessment was conducted using protocols developed by the Vermont River Management Program, which are designed to guide assessments through a series of phases that integrate information from an overarching watershed context down to project-specific scales, with each previous stage informing the successors. By assessing underlying causes of channel instability at both watershed and localized scales, and encouraging the stream's return to equilibrium conditions, management efforts can be directed toward long-term solutions that help curb escalating costs and reduce conflicts with ongoing stream processes. Phase 2 involves rapid field assessments on select reaches. A bridge and culvert survey was conducted in conjunction with this assessment for structures located on assessed reaches.

Assessment results are summarized in this report, and preliminary analysis is presented through the use of stressor, departure, and sensitivity analysis maps to integrate the findings in a more understandable and intuitive manner. This analysis informs a process designed to identify and catalogue technically feasible projects that can help reduce flood and erosion hazards along stream corridors, improve water quality and aquatic habitat, and enhance recreational opportunities.

Due to the current conditions in the Tyler Branch watershed, two factors were given the greatest weight when prioritizing projects:

1) Reduction of stream power
2) Accommodation of planform adjustments, permitting both
    a) Full meander development; and
    b) Room for channel avulsions and rapid lateral migrations

The particular importance of stream power in these dynamics means that the design and success of downstream restoration projects will be strongly affected by discharge and sediment loads higher in the watershed. Project prioritization thus emphasizes upstream restorations of equilibrium conditions whenever feasible.

The widespread distribution of the important stream assets needed for this restoration work makes parcel by parcel corridor protection efforts extremely challenging, and municipal bodies can achieve many of the same goals much more efficiently and effectively. The top priority recommendation in this report is thus for the Town of Enosburgh to consider incorporation of belt-width corridors or similar measures into town-wide planning efforts. The Town of Bakersfield adopted 100 foot development setbacks from streams at their March 2009 Town meeting.

Based on the results of the assessments, the following "short list" of projects, in recommended order of importance, was prioritized:

- Enosburgh: Incorporation of fluvial erosion hazard (FEH) zones or other belt-width corridors into town planning processes. March 2009 adoption of 100 foot stream setbacks in Bakersfield will largely avoid flood hazards and accommodate stream dynamics in the smaller streams there, but the larger sections of stream present on the Tyler Branch mainstem will need more room to accomplish these same objectives. FEH zones are highly recommended for their incorporation of stream dynamics in determining the width of the corridor required to accommodate these processes and ensure safety and the protection of investments by avoiding conflicts with these processes. Encroachments in these corridors are currently relatively limited, indicating good possibilities for streams to re-establish equilibrium conditions if further encroachments are prevented.

- Beaver Meadow Brook tributary in East Enosburgh, reaches T3S1.01 and T3S1.02: Address elevated flow impacts through:

  a) assessment of the status of historic stream diversion on Horseshoe Circle near Bluto Rd. for potential restoration of wetland attenuation functions (west side of Horseshoe Circle) on a tributary that may be currently diverted to this stream, or incorporate elevated flows into planning (essentially increasing the importance of items b) and c) below as well as the adoption of FEH zones or similar planning to ensure safety and protection of investments by limiting encroachments)

  b) Buffer plantings (especially trees rather than shrubs) near Longley Bridge Rd. bridge, primarily to provide structural diffusion of stream power in flood flows and help moderate the duration of and rate at which elevated flow impacts enter the stream and transfer to downstream; and

  c) corridor protection and/or forest management plan amendments upstream to help maintain the integrity of wooded buffers that are currently providing these benefits (structural diffusion of stream power in flood flows, moderation of the duration and rate at which elevated flows impact the stream), but have experienced some streamside cutting; emphasize retention of woody buffers unless particular trees are critical to the economic viability of a logging job

- Further bridge assessment at Witchcat Rd., west of the Joyal Rd. intersection, regarding possible replacement (in reach T2.04 of the Bogue Branch): potential safety issue regarding structural fatigue, with possibilities for addressing significant constriction and alignment issues if this bridge needs to be replaced

- Tyler Branch mainstem reach M13, above the confluence with Beaver Meadow Brook in East Enosburgh:

  a) explore options for channel management easements and/or forest management plan amendments to maintain the stream's ability to store flow and sediment loads; importance amplified by elevated stream power related to "cleaning out" and straightening of the channel and apparent possibility of expansion at Brookside Campground that may further constrain lateral adjustments of the stream

b) town road ditch remediation upstream of the Sand Hill Rd. bridge to reduce or slow direct stormwater inputs to the stream

- Ross Brook reach T2S1.04 above and below East Bakersfield Rd. bridge: fencing, buffer retention and augmentation, corridor protection; this is a naturally occurring high deposition zone that can play an important role in storing flow and sediment loads elevated by land use changes further upstream
- Approach landowners in reaches T2S1.04 on Ross Brook (Branon sugarbush) and M14 on Tyler Branch (Wright Farm) about options for arresting headcuts, initiated during 2008 flash flooding, that could undercut private roads (farm and sugarbush roads); higher priority on T2S1.04, where these headcuts may contribute to loss of floodplain that is important for storing flow and sediment loads that will otherwise increase impacts on downstream areas

Pertinent analysis contributing to these recommendations and understanding of overall watershed dynamics indicates that:

- Stream power elevated by a variety of factors is heightened by the effects of "sediment starving", particularly of coarse sediments, at dams on The Branch, Bogue Branch and Tyler Branch
- This heightened stream power contributes to elevated flood hazards and stream adjustment processes in downstream portions of the watershed
- These impacts are difficult to remediate downstream, increasing the importance of opportunities for attenuating flow in upstream reaches in particular
- Good opportunities for attenuating both flow and sediment loads exist at naturally occurring high deposition zones, but attenuating these loads makes it important to accommodate lateral movement of the stream (which often appears to occur across the entire valley floor over time)
- Channel straightening and gravel removal are contributing to elevation of the increased stream power impacts passed downstream
- Coarse bed and bank materials predispose the streams in eastern portions of the watershed (approaching the Cold Hollow Mountains) to channel avulsions and rapid lateral migration as a primary means of channel evolution, placing a premium on minimizing corridor encroachments both to accommodate stream processes and for flood hazard avoidance and mitigation

A more complete table of prioritized projects can be found in Section 6.2 (Project Prioritization) of this report. A "catalogue" of projects, with varying priorities, can be found with the reach descriptions in Section 6.1. Primary analysis summaries are found in the section 5.1.4 *Existing Sediment Regime Summary* and Section 5.2 Sensitivity Analysis.

2.0 INTRODUCTION

In May, 2008 the Northwest Regional Planning Commission (NRPC) engaged Redstart Forestry and Consulting to conduct Phase 2 geomorphic assessments on twenty stream reaches (reaches are portions of the stream with similar characteristics in terms of channel geometry, valley, and floodplain settings) within portions of the Tyler Branch watershed in Franklin County, VT. The Tyler Branch is a tributary of the Missisquoi River, and this assessment is a part of larger effort to enhance the health and vitality of Vermont streams and rivers and the communities they support, including efforts by international, federal, state, local and individual partners to improve the water quality within Missisquoi Bay and Lake Champlain. According to the Missisquoi River Basin Association (MRBA),

> **Missisquoi Bay** drains 1,200 square miles of northwestern Vermont and southern Quebec….
>
> In addition to draining the Missisquoi River's 88-mile course and its over 50-miles of tributaries (Black Creek, Trout River, the Tyler Branch, and Mud Creek), Missisquoi Bay also drains the Pike and Rock Rivers.
>
> Our land use practices over the past centuries in the watershed have led to a degradation of the water quality in the river and the bay. Missisquoi Bay alone now accounts for over one third of all the non-point source phosphorus in Lake Champlain, more than all the other Vermont watersheds put together!
>
> Phosphorus runoff, which comes from many sources including eroding stream banks and a lack of buffers on worked fields, promotes excessive algae growth and impairs water quality. Algae blooms in the bay in recent years have been severe enough to close beaches, impact tourism, and in some cases kill pets. (MRBA 2009)

Algae blooms in the bay have also coincided with some very wet years in Vermont, which complicates this picture, but these factors do appear strongly tied to watershed and stream dynamics in the Tyler Branch and wider Missisquoi basins.

The 2008 Tyler Branch Phase 2 assessment was based on protocols developed by the Vermont River Management Program (VT-RMP geoassesspro 2007), which are designed to guide assessments through a series of phases that integrate information from an overarching watershed context down to project-specific scales, with each previous stage informing the successors. By assessing underlying causes of channel instability at both watershed and localized scales, and encouraging the stream's return to equilibrium conditions, management efforts can be directed toward long-term solutions that help curb escalating costs and efforts directed toward resolving conflicts with ongoing stream processes. Phase 2 involves rapid field assessments on select reaches.

Assessment results are summarized in this report, and preliminary analysis (in conjunction with additional data collected in 2006) is presented through the use of stressor, departure, and sensitivity analysis maps to integrate the findings in a more understandable and intuitive manner. This analysis informs a stepwise process designed to identify and catalogue technically feasible projects that can help reduce flood and erosion hazards along stream corridors, improve water quality and aquatic habitat, and enhance recreational opportunities.

2.1 PROJECT OVERVIEW

NRPC issued its 2008 Request for Proposals for Phase 2 Assessment in the Tyler Branch watershed based on River Corridor Grant funding from the Vermont Department of Environmental Conservation, Agency of Natural Resources River Management Program (VT-RMP). These grants are a primary tool in helping communities employ a science-based approach to achieve VT-RMP's stated goal of managing toward, protecting, and restoring the fluvial geomorphic equilibrium condition of Vermont's rivers and streams as a means to help resolve conflicts between human investments and river dynamics in an economically and ecologically sustainable manner (VT-RMP RCPG 2007; VT-RMP Alternatives 2003).

- Fluvial: of or related to rivers and streams (i.e., flowing waters)
- Geomorphology: Geo = earth; morphology = shape

The science of geomorphology looks at how water and sediment move within the landscape, both in space and over time. Extensive experience and observation indicate that a stream in equilibrium will erode its banks and change course only minimally, even in flood situations. If a stream becomes "unbalanced", however, it will begin a series of adjustments that may include changes in course, slope, depth, or width—or all four—until it becomes balanced again (Fig. 1; VT-RMP Fact Sheet1 2003). Geomorphic assessments help determine expected reference conditions for a stream (based on the physical dictates of the stream's hydrology and landscape setting), whether the stream has departed from those reference conditions, and if so, at what stage the stream is in the process of the adjustments required to regain equilibrium.

River Corridor Protection and Management

FACT SHEET ①

Vermont DEC River Management Program

Overview

Vermont towns, like many others in America, were, for the most part, established and developed along rivers and waterways. Before roads and electricity, the benefits of a river as a source of transport and power far outweighed the risks of flooding for most settlements. As towns and communities have grown, so have the costs of flood damage.

The past century has been one of great change for Vermont's waterways. Early in the century many watersheds were cleared of forests, river systems have been straightened and channelized and sediment and erosion have become an increasing problem. Works, large and small, have been carried out to allow for roads, railways and bridges, and to repair flood damage.

Tyler Branch in Enosburg, Vermont

Figure 1. Excerpt from a VT River Management Program fact sheet features a location in the Tyler Branch watershed illustrating the type of catastrophic changes that can occur during flooding on an out-of-balance stream.

A Phase 1 Stream Geomorphic Assessment (see section 4.1 of this report for further description of the geomorphic assessment process and phases) was completed for the Tyler Branch watershed by the Lake Champlain Committee in 2003. In 2005, the MRBA hired the Johnson Company to complete a Phase 2 Assessment on 10 reaches of the Tyler Branch and 10 reaches of The Branch, a major tributary to the Tyler Branch. That Phase 2 Assessment indicated large amounts of sediment storage in the assessed streams that did not appear fully explained by the amount of erosion observed in those same areas (Johnson (MRBA) 2006).

Reaches for the Tyler Branch watershed 2008 Phase 2 Assessment (Fig. 2) were selected by project partners including representatives of NRPC, MRBA, VT-RMP, VT Clean and Clear, Partners for Fish and Wildlife, and the VT Agency of Agriculture/ US Department of Agriculture Conservation Reserve Enhancement Program. Informed by results of the previous assessments, the reaches were selected to help identify projects that could be implemented for a variety of objectives contributing to protection and restoration efforts in the watershed, with a particular emphasis on providing information requested for planning assistance in the towns of Enosburgh and Bakersfield. Reach T1S4.01 on Beaver Meadow Brook on the Bakersfield/Enosburgh town line was not included because project implementation (buffer establishment and relocation of primary cattle travel corridors away from the stream) was already occurring there. Reach T1.14 on The Branch, southeast of Bakersfield village, was not included because preliminary assessments indicated the reach is dominated by beaver meadows and wetland with few impacts, and preference was thus given to reaches indicating a greater need for assessment.

3.0 BACKGROUND INFORMATION

3.1 GEOGRAPHIC SETTING

3.1.1 Watershed description

The Tyler Branch watershed drains roughly 58 sq. mi., and comprises a large portion of the southern flank of the Missisquoi River in the lower third of that river’s overall watershed (Fig. 2). The overall Missisquoi basin drains nearly 1200 sq. mi., in northern VT and southern Quebec, into Missisquoi Bay and Lake Champlain. The Tyler Branch watershed ranges in elevation from roughly 360 ft. above sea level, at the confluence of the Tyler Branch and the Missisquoi River in the northwest corner of the watershed, to more than 3000 ft. elevation in the headwaters areas in the Cold Hollow Mountains near the Bakersfield/Montgomery town line.

Elevations for reaches included in the 2008 Phase 2 assessment ranged from roughly 490 ft at the confluence of the Bogue Branch and the Tyler Branch (3/4 mi. east of West Enosburgh on the Tyler Branch Rd.) to about 1560 ft at the top of Ross Brook, located in a saddle between Peaked Mountain and the Cold Hollow Mountains near the Bakersfield/Belvidere town line. Although other reaches selected for 2008 Phase 2 assessment lay in disjunct portions of the watershed (Fig. 2), elevations ranged within these limits.

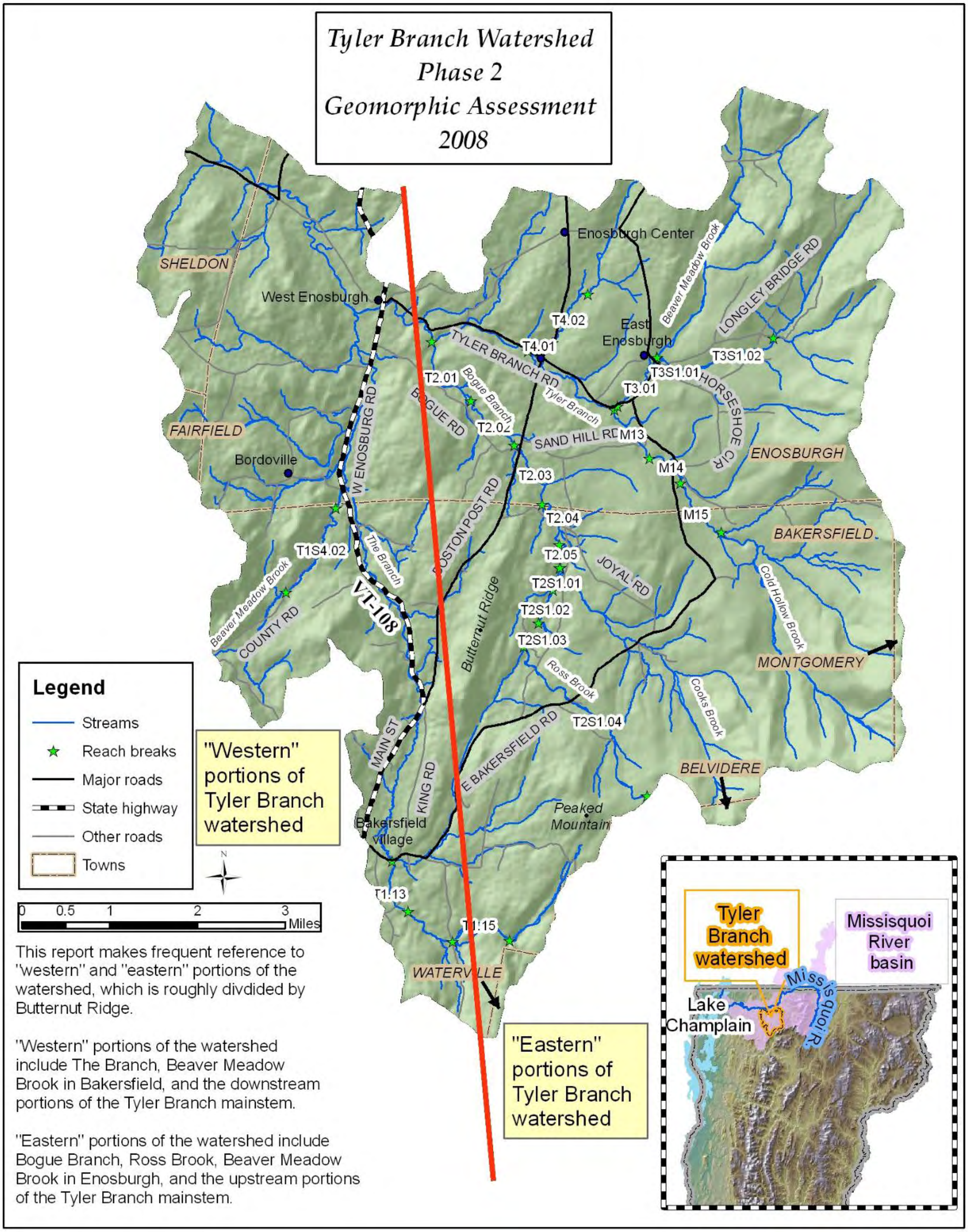


Figure 2. Overview of the twenty stream reaches (labeled by reach number) included in the 2008 Phase 2 Assessment within the Tyler Branch watershed.

3.1.2 Political jurisdictions

All stream reaches assessed in 2008 Phase 2 assessments are located in Enosburgh and Bakersfield; both of these towns are within Franklin county. The overall Tyler Branch watershed lies largely within the towns of Enosburgh and Bakersfield, along with a significant portion of Sheldon and smaller portions of Fairfield, Waterville, Belvidere, and Montgomery (Fig. 2). Sheldon, Enosburgh, Bakersfield, Fairfield and Montgomery are within the region covered by the Northwest Regional Planning Commission; Waterville and Belvidere are covered by the Lamoille County Planning Commission.

3.1.3 Land use history and current general characteristics

An excellent general background treatment and analysis of the overall Missisquoi River sub-basin, including the Tyler Branch watershed, has been drafted by the USDA Natural Resources Conservation Service and partners as part of the Missisquoi Areawide Plan (USDA-NRCS MAP 2008), pertinent points of which are included (as indicated) here.

The headwaters areas of the Tyler Branch watershed, backing up to the Cold Hollow Mountains, are included among the more rugged parts of the Misssisquoi basin, a fact that contributes to the watershed being predominantly forested (Fig. 3). According to circa 2001 land cover/land use analysis derived from satellite imagery (Troy et al. 2007), the Tyler Branch watershed at the turn of the 21st century is roughly 76% forested, and agricultural land use in the watershed occupies roughly 17% of the land base (Table 1). A smaller proportion of the drainage basin is developed, with roughly 6% combined "urban" and "urban open" land uses. "Urban" in this context refers to not only densely developed areas, but roads, suburbs and large-lot residential development as well (Troy et al. 2007).

Using an eight-class system utilized in a 2007 updated analysis of 2001 land cover/land use data (Troy et al. 2007), the Tyler Branch indicates slightly lower than average agricultural and "urban" land uses in comparison with all the subwatersheds in the greater Missisquoi sub-basin, with an above-average percentage of the watershed forested (Table 1). Figure 3 gives a visually simplified version (using just four broad classes) of the same satellite imagery (UVM-SAL 2001). Although the percentage of wetlands in the Tyler Branch watershed is below average for the Missisquoi basin (Table 1), it is notable that these wetlands, along with hydric soils present in the basin, overlap heavily with areas of agricultural and "urban" use (i.e., cleared lands; Fig. 3). The import of this factor is further discussed in Section 5.1.1 (Watershed-scale hydrologic regime stressors) of this report.

Table 1. Land cover/land use data for the Tyler Branch watershed compared with mean values and ranges from all subwatersheds in the greater Missisquoi sub-basin, derived from circa 2001 satellite imagery (excerpted from Appendix D, Troy et al. 2007).

		Urban	Agricult.	Brush	Forest	Water	Wetland	Barren	Urban Open
	Tyler Branch	4.1%	16.9%	1.2%	75.6%	0.1%	0.3%	0.0%	1.8%
Missisquoi Basin subwatersheds	Mean (± std_dev)	5.4% ± 2.6%	21.6% ± 13.4%	2.2% ± 0.8%	65.0% ± 18.1%	1.6% ± 4.3%	2.0% ± 3.8%	0.2% ± 0.5%	1.9% ± 1.6%
	Minimum	2.8%	2.7%	1.0%	30.4%	0.0%	0.1%	0.0%	0.0%
	Maximum	13.7%	51.9%	3.6%	91.3%	19.8%	16.5%	1.9%	7.2%

Portions of the watershed include less steep agricultural soils (with relatively few stones) concentrated along the larger streams, pockets of ancient lake sediments (often with associated hydric soils; Fig. 3), and level high terraces left by glacial action in some valleys, which contribute to the dominance of dairy agriculture as the leading industry in the area. Broad-scale trends in the Missisquoi sub-basin "do not express a likely reduction in the number of, but indicate a trend toward larger dairy operations, and an increase in the number of smaller, more diversified farms. In general, dairy farms in these counties are increasing in size, both in cropland acres and in livestock numbers, while the overall number of dairy operations has decreased" (USDA-NRCS MAP 2008).

The hilly to steep topography of the Tyler branch basin features less intensively cultivated cropland than the mainstem Missisquoi and subwatersheds closer to Lake Champlain and the plateau in the upper portions of the Missisquoi Basin. Still, the Tyler Branch watershed reflects many of the broad-scale trends within the dairy industry noted as key points in the Missisquoi Areawide Plan[1]:

- The acreage of harvested cropland (hay and corn) in Franklin County was fairly steady from 1974-2002.
- Both the NRI and Census data suggest a significant increase in corn acreage in Franklin County over 15 and 28-year time frames from 1974-2002.
- The Missisquoi Sub-basin has some of the highest concentration of farmland and dairy cows in Vermont. An estimated 29.5% of the Franklin County area is in agricultural use/cover and it houses ¼ or more of the State's cows.

("key points" from the Missisquoi Areawide Plan continue after Fig. 3)

1 The "key points" noted here for the Missisquoi basin are based on two data sources: the National Resources Inventory, conducted by NRCS, and the Census of Agriculture, conducted by the National Agricultural Statistics Service (USDA-NRCS MAP 2008).

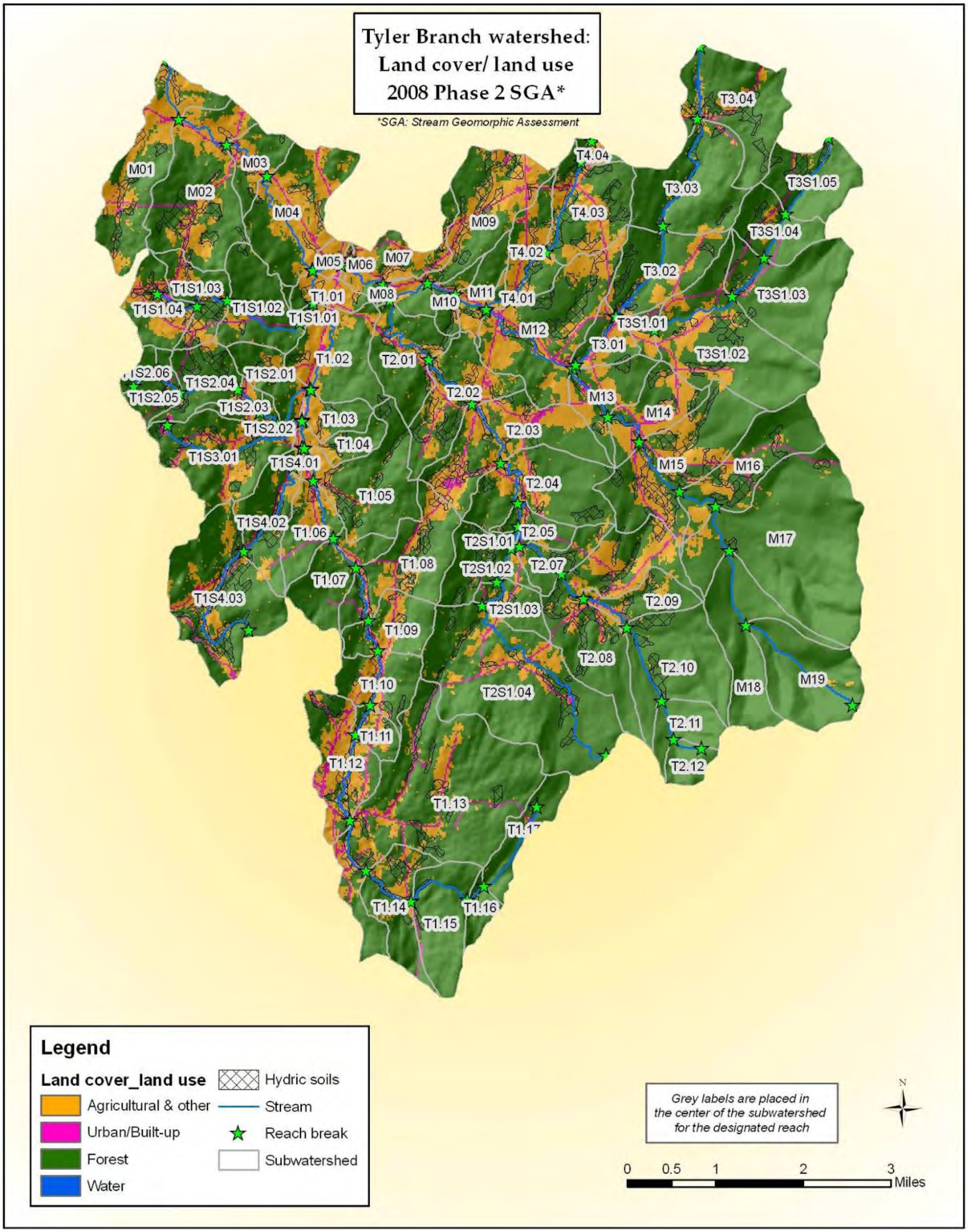


Figure 3. Visually simplified (four-class) land cover/land use analysis based on satellite imagery (UVM-SAL 2002) indicates roughly three-quarters of the watershed is forested, with significant agricultural use (~17%) and a lower proportion of developed land (~6%).

(“key points” from the Missisquoi Areawide Plan, continued)

- Franklin County is the only Vermont county where the number of dairy cows increased from 1974-2002.
- Compared to other counties, Franklin has the least amount of cropland per head of cattle.
- Developed land increased by about 25% in the Missisquoi Sub-basin from 1982-1997, growing from about 13,800 to 17,200 acres over that time.
- About 1,500 acres (40%) of the new built-up land came from cropland and pasture, and about 2,200 acres (58%) came out of forestland.

Enosburg Falls (census 2000 pop. ~1,500), located just north of the Tyler Branch watershed on the Missisquoi mainstem, is one of the larger villages in the overall Missisquoi sub-basin and as such is a center for light manufacturing, agriculture and agricultural supplies and services, and other skilled service industries. Recreation and tourism also contribute to the local economy (USDA-NRCS MAP 2008). St. Albans (combined City and Town census 2000 pop. ~15,000) and Swanton (census 2000 pop. ~6,000) are both within an hour commute of the Tyler Branch watershed, have close proximity to the Interstate-89 travel corridor, and offer further economic opportunities (manufacturing and importing businesses among others) that have likely contributed to some additional development pressure within the Tyler Branch watershed (Harper 2009). Generally, however, development pressures do not appear to be as acute in the Tyler Branch watershed as some other portions of Vermont.

3.2 GEOLOGIC SETTING

The headwaters of the Tyler Branch watershed are found in the Cold Hollow Mountains, from whence the watershed drops to the foothills and lower terraces (“Piedmont”) lying to the west of this northern end of the Green Mountain range. The uplands are dominated by bedrock and glacial deposits, while lower elevations include lake terraces and lacustrine sediments from an ancient sea filling portions of the overarching Missisquoi valley (USDA-NRCS MAP 2008). As noted in previous Phase 2 assessment reporting,

> “…the area has been periodically covered by glaciers, the most recent of which occurred from approximately 10,000 to 30,000 years ago. Bedrock in the study area is dominated by a combination of the Underhill and Pinnacle Formations which are composed of various types of quartzite (Doll 1961). The surficial geology is comprised of glacial tills and fluvial gravels and sands (Stewart and MacClintock 1970)….” (Johnson (MRBA) 2006)

The bedrock geology is quite variable within the watershed, and the Underhill and Pinnacle Formations in this area also include greenstones, slates, and dolomite. The moderately calcareous dolomite contributes to somewhat sweeter soils in localized areas, favorable for agriculture and forest growth, but in general these rock formations tend to be somewhat acidic. The quartzites that dominate these formations represent metamorphosized beach sands from the upper edges of the ancient sea that filled portions of the area, as well as subsequent lakes left in dammed areas as glaciers retreated. The greenstones and slates represent metamorphosed “mudstones” laid down along the shelf in slightly deeper portions of these water bodies (Thompson and Sorenson 2001). These materials form dense but sometimes friable bedrock (particularly the mudstones; Fig. 4) in portions of the watershed that contributes coarse substrates to the streams, augmenting more weathered cobbles left by glacial deposition. In areas where coarse substrates dominate, the stream beds can be relatively resistant to erosion and predispose the streams to channel avulsions and rapid lateral migration in high flows. This was particularly notable during the 2008 Phase 2 assessment in reaches M13 and M15 on the Tyler Branch, T2S1.04 on Ross Brook, and T1.15 on The Branch (see section 3.3 of this report, Geomorphic setting, for further discussion of "reaches").

Figure 4. Dense but friable "mudstones" (primarily slates here) in reach T1.15, along with similar materials in other portions of the watershed, have contributed coarse sediments to stream beds that are relatively resistant to erosion and predispose streams to channel avulsions and lateral migration instead of bed downcutting, but will erode in major floods.

It should be further noted, however, that the surficial geology of the area is also highly variable. Glacial advance (from northwest to southeast) was pinned against the foothills and ridges of the Tyler Branch basin and built up thick layers of ice before glaciers were able to pass over the Green Mountains to the east of the watershed, and the glacier's retreat occurred at different rates in response to the thickness of ice in any given area (Connally 1970; MacClintock 1970). Independent movement of surface ice floes occurred at times, while deeper layers of ice in some valleys remained locked in place, resulting in highly localized deposition processes when the ice finally retreated. Remarkably large boulders and other coarse materials were "rafted" on glacial ice into reaches such as T2.02 on Bogue Branch, T3.01 on Beaver Meadow Brook (Enosburgh) and T4.01, a tributary of the Tyler Branch, again contributing to streambeds resistant to erosion (but still erodible in major floods). Fluvial gravels and sands in terraces along valley sidewalls in these areas are frequently ice-contact formations (such as kame terraces, formed of unconsolidated materials of varying sizes dropped in place as the ice melted) or outwash plains and deltas (deposited in valleys by meltwaters during glacial retreat) in others. Importantly (in terms of erosion and deposition processes), the formations in narrow and/or deep valleys appear to only infrequently be till formations formed by glacial scouring (Connally 1970; MacClintock 1970); the result is unconsolidated materials that can be initially resistant to erosion by virtue of their coarseness, but will erode quickly under very high flows. Classic gully formation in such areas was observed during 2008 in reach M14 on the Tyler Branch (Fig. 5), while less dramatic incision was observed below stormwater inputs and field ditches in M14 as well as reaches T2.03 and T2.04 on Bogue Branch, T2S1.04 on Ross Brook, and T3S1.02 on a tributary off of Beaver Meadow Brook (Enosburgh) among others.

Figure 5. This classic gully, ~200 feet in length, opened in unconsolidated geologic materials along a valley wall of reach M14 on the Tyler Branch during an intense storm in a very wet summer 2008.

This complex tapestry of bedrock and surficial geology is reflected in the current variability of stream and landscape dynamics within the Tyler Branch watershed, with reaches included in the 2006 and 2008 Phase 2 assessments ranging from very broad valleys on deep alluvium or lake sediments to steep confined valleys on shallow-to-bedrock substrates (Fig. 6; Table 2). While 14 of the 20 reaches assessed in 2006 had flat or hilly valley side slopes, 18 of 20 of the reaches assessed in 2008 had at least one valley wall in the steep to extremely steep category (Table 2). With unconsolidated glacial materials often present in these slopes, large amounts of sediment can be moved suddenly during flash floods and high flows in the upstream portions of the Tyler Branch watershed. Mass failures, channel avulsions, and gully formation were all observed during the 2008 Phase 2 assessments, when a very rainy summer contributed to saturated soils in June and July and was followed by at least one (possibly more) intense localized storm (pers. observation). Major floods also appear to have occurred in the Tyler Branch watershed in 1997 and 1998 (see Sec 3.4.x, Flood history, of this report). Fine gravels and sands can be transported relatively quickly through the watershed in these events, and appear to be contributing to the formation of unstable sediment deposits in downstream reaches, as noted in previous Phase 2 assessment (Johnson (MRBA) 2006). Coarser materials are being moved through the watershed at a slower rate during high flows, and were sometimes observed as sediment “slugs” during the 2008 field work. In addition, Phase 2 reaches assessed in 2008 contain some significant impediments to sediment continuity between upstream and downstream reaches, which is further discussed in Section 5.1.2, Watershed-scale sediment regime stressors, of this report.

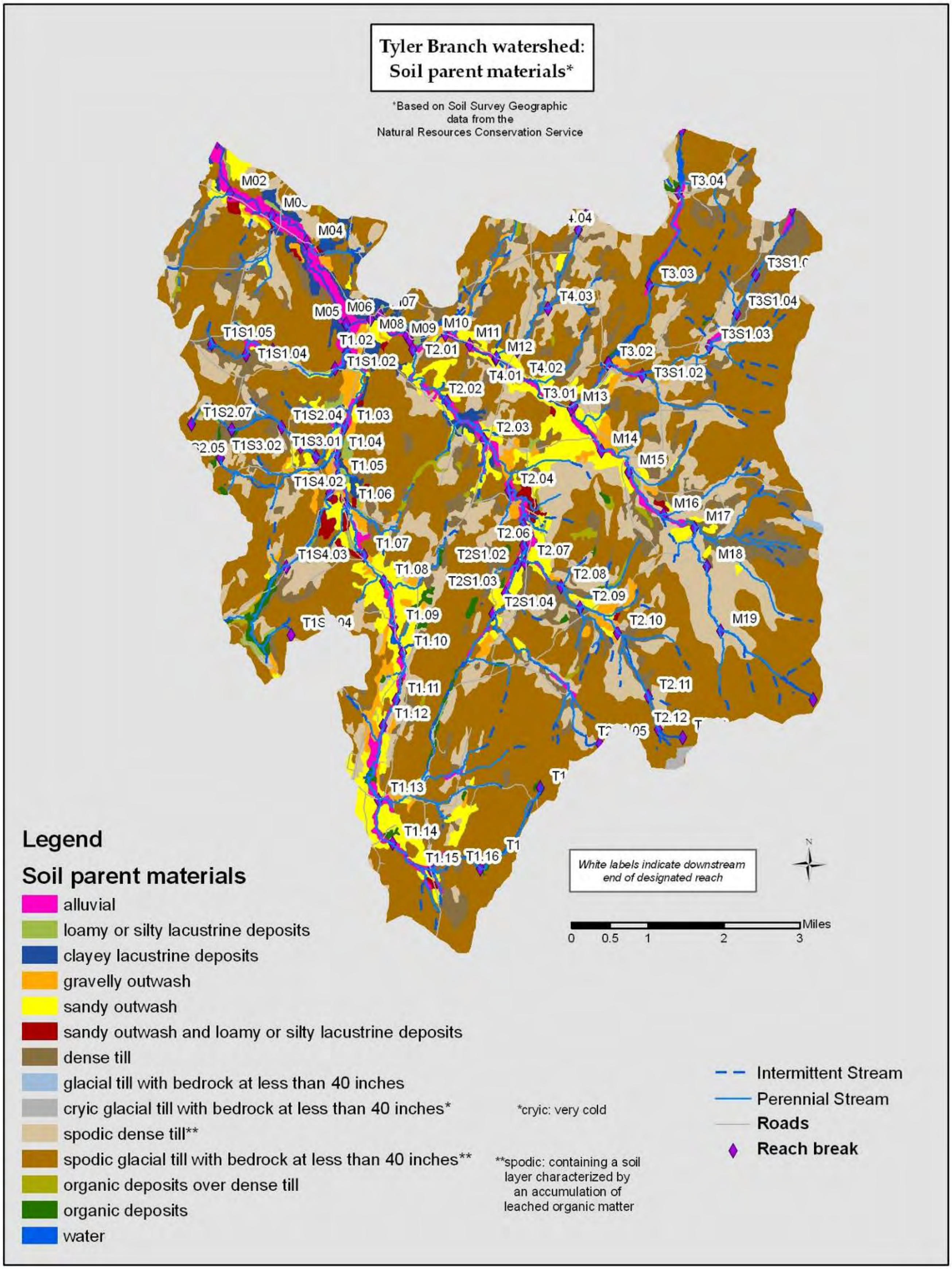


Figure 6. Soil parent materials map for the Tyler Branch watershed.

Table 2. Tyler Branch basin geologic characteristics for Phase 2 reaches excerpted from Phase 1, Step 3 (geology) report. Gray highlights indicate reaches included in 2008 Phase 2 Assessments; unhighlighted reaches were included in 2006 Phase 2 Assessments.

(**https://anrnode.anr.state.vt.us/ssl/sga/phase1_reports.cfm?pid=55&option=report&menu=none&report=30**)

Step	3.1	3.2	Valley Side Slope	
Reach ID	Alluvial Fan	Grade Control	Left	Right
Tyler Branch mainstem				
M01	None	None	Flat	Flat
M02	None	None	Steep	Steep
M03	None	None	Hilly	Steep
M04	None	Ledge	Flat	Flat
M05	None	Ledge	Flat	Flat
M07	None	Ledge	Flat	Flat
M09	None	None	Hilly	Hilly
M10	None	Ledge	Flat	Flat
M11	None	Ledge	Flat	Flat
M12	None	Waterfall	Flat	Flat
M13	None	None	Steep	Steep
M14	None	Multiple	Very Steep	Steep
M15	Yes	None	Extremely Steep	Extremely Steep
The Branch				
T1.01	None	Ledge	Flat	Flat
T1.02	None	None	Flat	Flat
T1.03	None	None	Flat	Extremely Steep
T1.04	None	Multiple	Flat	Flat
T1.05	None	Multiple	Flat	Flat
T1.06	None	Ledge	Flat	Flat
T1.07	None	None	Flat	Flat
T1.08	None	Multiple	Very Steep	Very Steep
T1.10	None	None	Steep	Steep
T1.11	None	Multiple	Steep	Steep
T1.13	None	None	Steep	Very Steep
T1.15	Yes	Multiple	Extremely Steep	Extremely Steep
Beaver Meadow Brook (Bakersfield)				
T1S4.02	None	Ledge	Very Steep	Very Steep

Step Reach ID	3.1 Alluvial Fan	3.2 Grade Control	Valley Side Slope Left	 Right
Bogue Branch				
T2.01	None (masked?)	Multiple	Extremely Steep	Hilly
T2.02	None	Ledge	Steep	Hilly
T2.03	None	None	Flat	Flat
T2.04	None	Ledge	Steep	Steep
T2.05	None	Dam	Extremely Steep	Flat
T2S1.01	None	None	Extremely Steep	Hilly
T2S1.02	None (masked?)	Ledge	Extremely Steep	Extremely Steep
T2S1.03	None	Ledge	Steep	Steep
Ross Brook				
T2S1.04	Yes	Multiple	Steep	Steep
Beaver Meadow Brook (Enosburgh)				
T3.01	Yes	Multiple	Steep	Very Steep
Unnamed tributary of Beaver Meadow Brook (Enosburgh)				
T3S1.01	Yes	None	Very Steep	Hilly
T3S1.02	None	Multiple	Steep	Steep
Unnamed tributary of Tyler Branch				
T4.01	Yes	Ledge	Extremely Steep	Extremely Steep
T4.02	None	None	Hilly	Hilly

3.3 GEOMORPHIC SETTING

For the purpose of geomorphic assessment and corridor planning, streams in the study area were divided into “reaches,” twenty of which were included in the 2008 Phase 2 assessment discussed in this report. A reach is a relatively homogenous section of stream, based primarily on physical attributes such as valley confinement, slope, sinuosity, dominant bed material, and bed form, as well as predicted morphology based on hydrologic characteristics and drainage basin size. Classification parameters pertinent to establishing these reference types are listed in Table 3.

Table 3. Reference stream type summary indicating classification parameters pertinent to Tyler Branch watershed reaches included for 2008 Phase 2 assessment (VT-RMP geoassesspro 2007, Phase 1 Protocols, p. 28).

Reference stream type	Confinement (Valley Type)	Slope
A	Confined (NC)	Very Steep: 4.0–6.5%
B	Confined or Semiconfined (NC, SC)	Steep: 3.0–4.0%
B	Confined, Semiconfined, or Narrow (NC, SC, NW)	Moderate–Steep: 2.0–3.0%
C or E	Unconfined (NW, BD, VB)	Moderate–Gentle: <2.0%

2008 Phase 2 field assessments included three mainstem reaches of the Tyler Branch (M13-M15); two reaches of The Branch (T1.13 and T1.15); one reach on Beaver Meadow Brook in Bakersfield (T1S4.02); five reaches on the Bogue Branch (T2.01-T2.05); four reaches in the upstream portions of Bogue Branch and into Ross Brook (T2S1.01-T2S1.04); one reach on Beaver Meadow Brook in Enosburgh and two on an unnamed tributary that feeds into it (T3.01, T3S1.01-T3S1.02); and two reaches on an unnamed tributary of the Tyler Branch in East Enosburgh (T4.01-T4.02). Fifteen of these twenty reaches were classified as C type streams under reference conditions, primarily with riffle-pool bedforms (Table 4). Two reaches (T1.13 on the Branch and T2.04 on Bogue Branch) were classed as E type riffle-pool streams. One reach on The Branch (T1.15: A type, cascade) and one on Ross Brook (B type, step-pool) were higher gradient streams.

Table 4. Reference stream types and geomorphic characteristics for Tyler Branch included in 2006 and 2008 Phase 2 assessments, excerpted from Phase 1, Step 2 (preliminary reference stream type) report. Gray highlights indicate reaches included in 2008 Phase 2 Assessments; unhighlighted reaches were included in 2006 Phase 2 Assessments.

(https://anrnode.anr.state.vt.us/ssl/sga/phase1_reports.cfm?pid=55&option=report&menu=none&report=20)

Reach Number	Stream Type	Bed Form	Confinement (Valley Type)	Channel Slope (%)	Channel Length (ft)
Tyler Branch mainstem					
M01	C	Riffle-Pool	VB	0.2	4082
M02	C	Riffle-Pool	VB	0.1	3881
M03	C	Riffle-Pool	BD	0.2	3996
M04	C	Riffle-Pool	VB	0.3	7600
M05	C	Riffle-Pool	BD	0.7	1791
M07	C	Riffle-Pool	BD	0.7	3435
M09	C	Riffle-Pool	NW	1.1	3405
M10	C	Riffle-Pool	SC	1.4	1878
M11	C	Riffle-Pool	BD	0.9	2234
M12	C	Riffle-Pool	VB	1.1	7687
M13	C	Riffle-Pool	VB	2.2	3975
M14	C	Plane Bed	BD	2.4	3245
M15	C	Plane Bed	VB	1.9	4547

Reach Number	Stream Type	Bed Form	Confinement (Valley Type)	Channel Slope (%)	Channel Length (ft)
The Branch					
T1.01	C	Riffle-Pool	VB	0.4	2501
T1.02	C	Riffle-Pool	VB	0.5	6726
T1.03	C	Riffle-Pool	VB	1.5	2031
T1.04	C	Riffle-Pool	BD	0.8	1957
T1.05	C	Riffle-Pool	VB	1.1	2176
T1.06	C	Riffle-Pool	VB	1.0	4507
T1.07	C	Riffle-Pool	VB	1.0	2500
T1.08	C	Riffle-Pool	BD	1.3	3678
T1.10	C	Riffle-Pool	VB	0.5	3893
T1.11	C	Riffle-Pool	BD	0.3	2189
T1.13	E	Riffle-Pool	VB	0.5	4317
T1.15	A	Cascade	VB *	3.3	4619
Beaver Meadow Brook (Bakersfield)					
T1S4.02	C	Riffle-Pool	VB	0.4	7427
Bogue Branch					
T2.01	C	Riffle-Pool	BD	0.8	6539
T2.02	C	Riffle-Pool	BD	0.7	5109
T2.03	C	Riffle-Pool	VB	0.4	4632
T2.04	E	Riffle-Pool	VB	0.7	4627
T2.05	C	Riffle-Pool	VB	0.7	1884
T2S1.01	C	Riffle-Pool	VB	1.1	1572
T2S1.02	C	Riffle-Pool	NW	1.3	2263
T2S1.03	C	Riffle-Pool	NW	3.3	2739
Ross Brook					
T2S1.04	B	Step-Pool	BD*	5.5	14984
Beaver Meadow Brook (Enosburgh)					
T3.01	C	Riffle-Pool	VB	2.0	4350
Unnamed tributary of Beaver Meadow Brook (Enosburgh)					
T3S1.01	C	Riffle-Pool	VB	1.9	2748
T3S1.02	C	Riffle-Pool	BD	2.0	5899
Unnamed tributary of Tyler Branch					
T4.01	B	Step-Pool	SC	3.1	1789
T4.02	C	Riffle-Pool	VB	2.2	4454

***** Conflicting parameters, such as the Very Broad valley confinement for reach T1.15, an A type cascade stream (Table 4), or the Broad valley confinement for reach T2S1.04, a B type step-pool stream, generally indicate significant variation within the reach. This type of variation leads to the reach being further broken out into "segments" for assessment during the Phase 2 field assessments (see section 4, Methods, of this report for more information on the geomorphic assessment process).

A longitudinal profile of the Project area indicates gentle gradients along the lower reaches of the watershed (characterized by a dendritic fan shape), with gradients increasing primarily on the tributary “fingers” of the fan and upstream portions of the mainstem (Fig. 6; Table 4). The Tyler Branch mainstem gradually increases in slope from the base of the project area upstream to East Enosburgh (M12), where portions of the stream begin to increase in slope more significantly in the foothills of the Cold Hollow Mountains. These upstream portions contain some of the steepest slopes of the watershed. The Branch retains slope gradients of less than 2% from its confluence with the Tyler Branch right up through reach T1.15, approaching the limits of its extent in the watershed (Fig. 2), as does Beaver Meadow Brook in Bakersfield (an exception being a short portion of reach T1S4.02 with a steeper section of ledge grade controls that accounts for much of the elevational gradient on this stream).The other tributaries assessed in the 2008 Phase 2 assessment have steeper gradients in the area approaching the Cold Hollow Mountains in the eastern portion of the watershed (Table 4).

Ledge grade controls are interspersed throughout the watershed (Table 2), which has likely helped limit the degree of channel incision noted in the watershed. Alluvial fans are common in the eastern portions of the watershed at areas of significant slope gradient changes in the foothills of the Cold Hollow Mountains, and are likely present in the most downstream reaches of all tributaries assessed in 2008 (Table 2; “likely” because reach T2.01, the downstream end of Bogue Branch, has current land use and cover that masks whether the reach is actually an alluvial fan).

3.4 HYDROLOGY

3.4.1 Tyler Branch basin StreamStats

There are no continuous-record stream gages in the Tyler Branch drainage basin. The nearest gage of this type is upstream on the Missisquoi mainstem at East Berkshire, which drains a much larger basin (479 sq. mi. as opposed to 58 sq. mi. for the Tyler Branch watershed) but is located in a similar setting in terms of precipitation patterns. In reviewing the records at these stream gages, it is important to recognize the sometimes localized nature of storms that can have significant flood impacts. Due to the steep topography and shallow soils in the upland portions of the watershed, the Tyler Branch basin is predisposed to “flashy” flows in heavy precipitation events, and the peak flows associated with these types of storms are often attenuated on streams draining a larger basin (such as the situation at the East Berksire gage). While this is in part related to weather patterns, it is also important to recognize the impact of the topography and geology as well as changes in hydrology over time, as further discussed in Section 5.1 (Watershed hydrologic stressors) of this report.

The United States Geological Survey (USGS) administers a *StreamStats in Vermont* website, which is designed to help compute streamflow and drainage basin characteristics for ungaged sites (http://water.usgs.gov/osw/streamstats/Vermont.html). Figure 7 indicates the differences in basic characteristics for the Tyler Branch and Missisquoi mainstem (at East Berkshire) drainage basins as summarized in reports from that site.

Tyler Branch Basin Characteristics Report

Parameter	Value
Drainage Area (square miles)	58
Percent Lakes and Ponds (percent)	0.33
Percentage of Basin Above 1200 ft (percent)	22.7

Tyler Branch Basin Streamflow Statistics Report

Statistic	Flow (ft^3/s)
2_Year_Peak_Flood	1460
5_Year_Peak_Flood	2080
10_Year_Peak_Flood	2530
25_Year_Peak_Flood	3120
50_Year_Peak_Flood	3570
100_Year_Peak_Flood	4030
200_Year_Peak_Flood	5150

Missisquoi mainstem (near East Berkshire) Basin Characteristics Report

Parameter	Value
Area in square miles	479
Percent of area covered by lakes and ponds	0.0636
High Elevation Index - Percent of area with elevation > 1200 ft	35.2

Missisquoi mainstem (near East Berkshire) Data-Collection Station Report

USGS Station Number	04293500
Station Name	MISSISQUOI RIVER NEAR EAST BERKSHIRE, VT
Peak-Flow Statistics	**Flow (ft3/s)**
2_Year_Peak_Flood	9600.00
5_Year_Peak_Flood	12400.0
10_Year_Peak_Flood	14400.0
25_Year_Peak_Flood	17300.0
50_Year_Peak_Flood	19600.0
100_Year_Peak_Flood	22000.0
200_Year_Peak_Flood	24700.0
500_Year_Peak_Flood	28500.0

Figure 7. Comparison of peak streamflow and basin characteristics statistics reports for the Tyler Branch and Missisquoi mainstem (at East Berkshire) drainage basins, excerpted from the USGS StreamStats website.

3.4.2 Tyler Branch flood history

Flood history at the USGS East Berkshire data collection station indicates floods exceeding the 50-Year peak flow in 1927 (November 1927, which is counted as water-year 1928, exceeded the 500-year peak), 1982, and 1998 (Fig. 9, next page). A series of floods were recorded between 1992 and 1998, with flows exceeding the 10-year peak flow in six of those seven years. Three of those events exceeded the 25-year peak flow, including the 1998 flood which exceeded the 50-year peak flow (Fig. 9).

Fieldwork during 2008 also indicated very recent flash floods in the Tyler Branch watershed. In many portions of Vermont, June and July 2008 were the wettest records for those months in 114 years of record keeping (NOAA 2008), and the overall summer of 2008 was the third wettest on record for that same time span (NRCC 2009). Annual precipitation levels were the fifth highest on record in Vermont during 2008, with both high snow and rainfall recorded during the year throughout much of the northeast (NCDC 2009; Fig. 8).

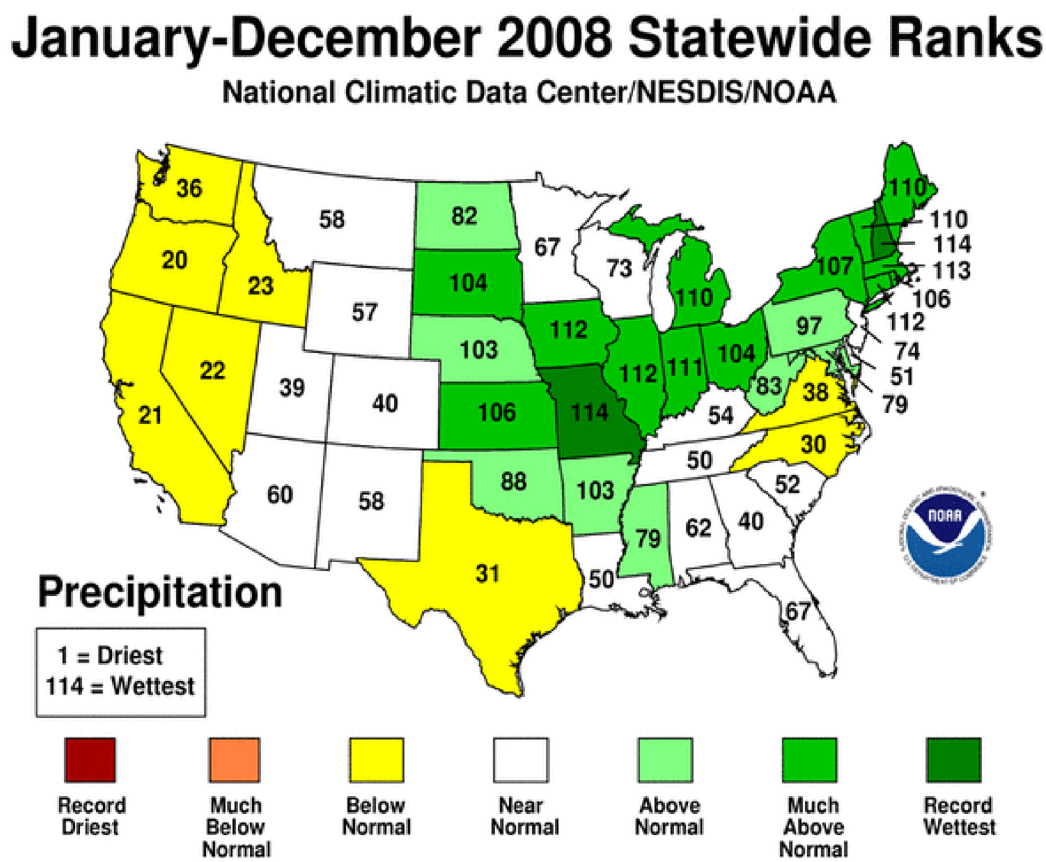


Figure 8. National Oceanic and Atmospheric Administration map indicating annual precipitation during 2008 was the fifth highest on record in Vermont; recent flash flooding was evident in the Tyler Branch watershed during 2008 fieldwork.

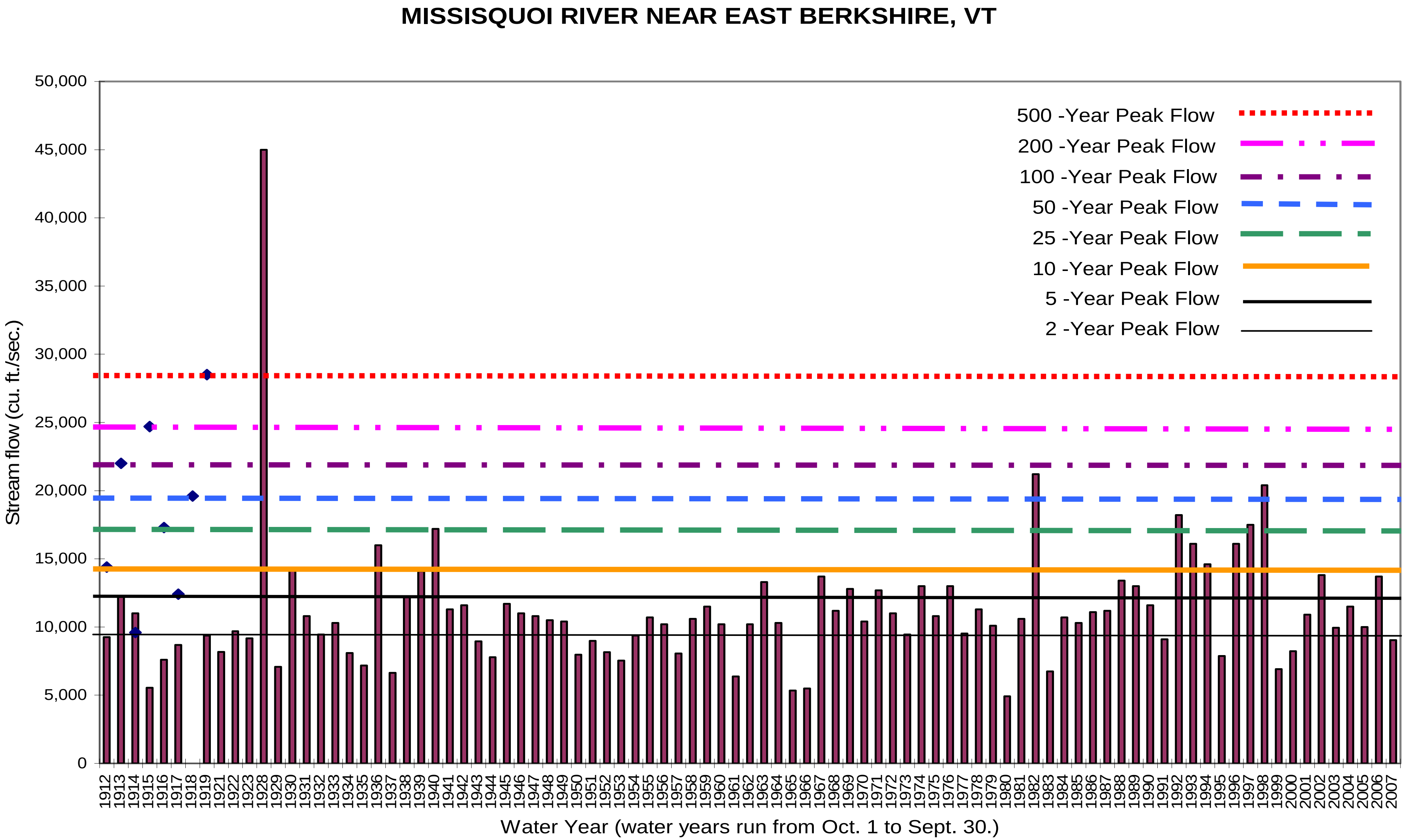


Figure 9. "Annual" (i.e., 2-Year) and flood-level peak streamflows at the USGS continuous-record stream gage on the mainstem of the Missisquoi River at East Berkshire.

While it is possible to say that the East Berkshire stream gage is located in a similar setting as the Tyler Branch watershed in terms of precipitation patterns, it is also important to recognize that there is significant variation in precipitation patterns within the Tyler Branch watershed. The headwaters of Bogue Branch and Tyler Branch, in the eastern portions of the watershed, and approaching the northern Green Mountains, have some of the highest annual precipitation levels in the state of Vermont (USDA-NRCS 2009). The majority of The Branch, in the western portion of the Tyler Branch watershed, is located in an area that tends to receive significantly less rainfall on an annual basis (Fig. 10).

3.5 ECOLOGICAL SETTING

The Tyler Branch watershed lies within the Champlain and Northern Green Mountains biophysical regions (Thompson and Sorenson 2001), with the southeastern third of the watershed, in the foothills of the Cold Hollow Mountains, being included in the latter. This more heavily forested and rugged terrain affords valuable wildlife habitat to a variety of species requiring relatively undisturbed core habitat. Although the Tyler Branch watershed also appears to host a healthy native fish population, and is periodically stocked with yearling brook trout (VT Dept. of Fish & Wildlife), fish passage from downstream along the Missisquoi mainstem is blocked by the hydroelectric dam at Enosburg Falls as well as other hydroelectric dams further downstream. Unusual geologic formations contribute to some high elevation ponds and wetlands in the upstream portions of the watershed (pers. obs.; pers. comm.., D. Allard, consulting ecologist, botanist and geographer, April 2009) but the ecology of these areas has not been extensively documented at this time.

Riparian habitat has been heavily influenced by human habitation in the last 200 years, with intensive agriculture and development largely occupying what would likely be floodplain forest habitats in the lower elevations of the watershed in particular. Beaver-impacted alder/herbaceous wetland habitats appear to have been less impacted than former floodplain forests in this watershed. Inclusions of mildly calcareous bedrock in the area support a good number of butternuts (a USDA Forest Service Region 9 sensitive species), particularly along the riparian corridor of Bogue Branch and adjacent hillsides in the vicinity of Butternut Ridge (Fig. 2). Although the large majority of these butternuts are declining due to the presence of butternut canker, there are current active interests in identifying potentially resistant trees that are staying healthy despite the omnipresence of the fungus responsible for butternut canker, as well as potential restoration habitat if such trees are identified (Michler et al. 2006).This tree is shade-intolerant, and open floodplain and agricultural areas as well as the locally abundant distribution in this area may indicate opportunities for such efforts.

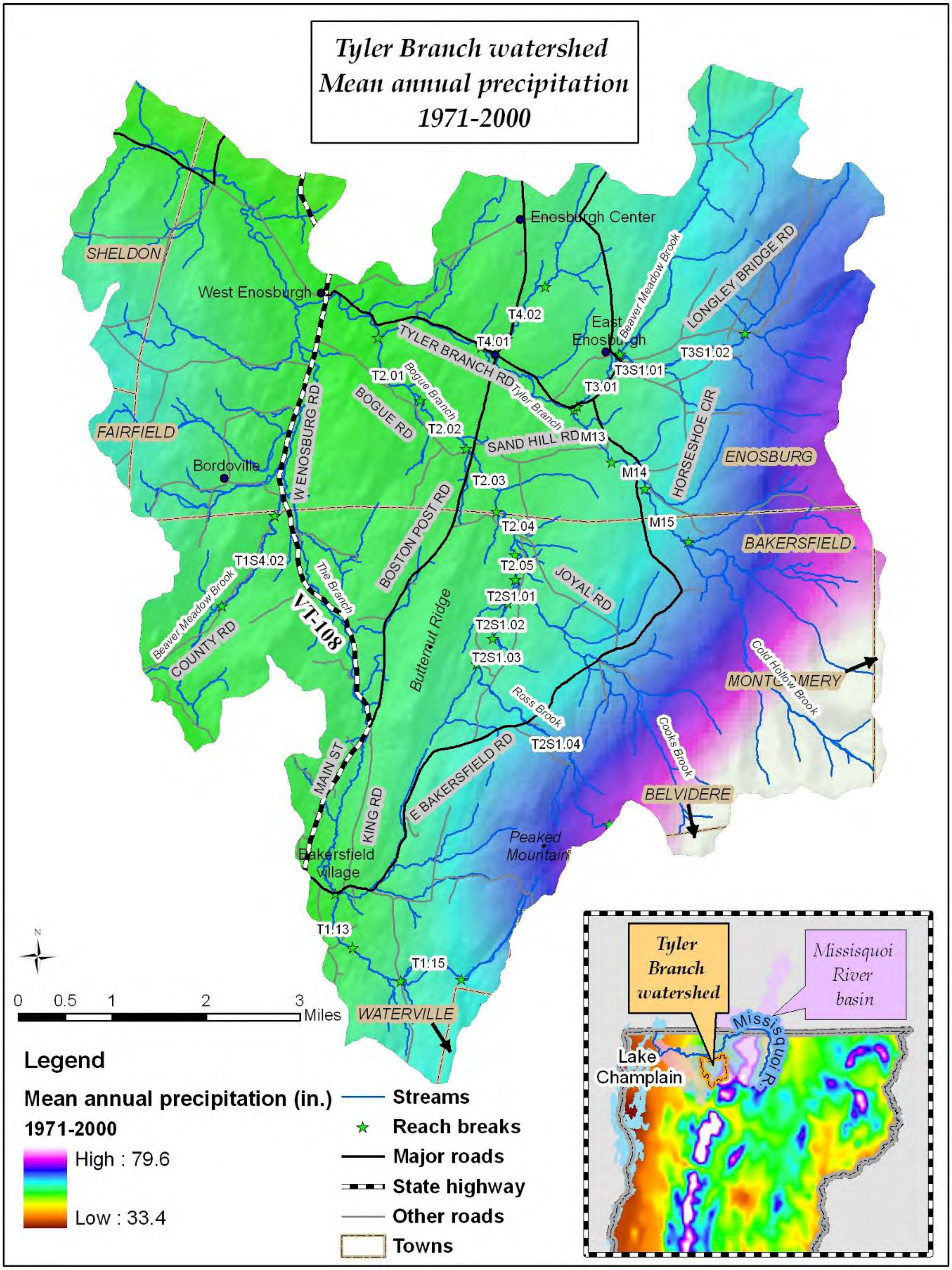


Figure 10. Mean annual precipitation map for Vermont indicates that the eastern portions of the Tyler Branch watershed receive some of the highest levels of combined rain and snowfall in Vermont (USDA-NRCS 2009).

4.0 METHODS

4.1 STREAM GEOMORPHIC ASSESSMENT

In an effort to provide a sound basis for decision-making and project prioritization and implementation, the Vermont Agency of Natural Resources has developed protocols for conducting geomorphic assessments of rivers. The results of these assessments provide the scientific background to inform planning in a manner that incorporates an overall view of watershed dynamics, as well as the reach-scale dynamics that have been a primary focal point of project planning in the past. Incorporating upstream and downstream dynamics in the planning process can help increase the effectiveness of implemented projects by addressing the sources of river instability that are largely responsible for erosion conflicts, increased sediment and nutrient loading, and reduced river habitat quality (VT-RMP RCPG 2007). Trainings have been held to provide consultants, regional planning commissions, and watershed groups with the knowledge and tools necessary to make accurate and consistent assessments of Vermont's rivers.

The stream geomorphic assessments are divided into phases. A Phase 1 assessment is a preliminary analysis of the condition of the stream through remotely sensed data such as aerial photographs, maps, and "windshield survey" data collection. This phase of work identifies a "reference" stream type for each reach assessed. Phase 2 involves rapid assessment fieldwork to inform a more detailed analysis of what adjustment processes are taking place, whether the stream has departed from its reference conditions, and how it might continue to evolve in the future. This sometimes requires further division of "reaches" into "segments" of stream, based on such field-identified parameters as presence of grade controls, change in channel dimensions or substrate size, bank and buffer conditions, or significant corridor encroachments. River Corridor Plans analyze the data from the Phase 1 and 2 assessments to inform project prioritization and methodology. Phase 3 involves detailed fieldwork for projects requiring survey and engineering-level data for identification and implementation of management and restoration alternatives.

As noted in the Project Overview, a Phase 1 Stream Geomorphic Assessment (SGA) was conducted for the Tyler Branch watershed in 2003. Based on the results of the Phase 1 assessment and interests of project partners, Phase 2 assessments were conducted by the Johnson Company on 10 reaches of the Tyler Branch and 10 reaches of The Branch, a major tributary to the Tyler Branch, in 2005. Combined results of the Phase 1 assessment, 2005 Phase 2 and 2006 analysis of that data, and interests of project partners informed the selection of reaches for the 2008 Phase 2 assessments, conducted by Redstart Forestry and Consulting. Data from all of these assessments have been entered into the most current version of the VT River Management Program (RMP) online Data Management System ("DMS"; https://anrnode.anr.state.vt.us/ssl/sga/security/frmLogin.cfm), where they are available for public viewing. Phase 1 data were updated, where appropriate, using the field data from the Phase 2 assessment; these changes are tracked and documented within the DMS. Spatial data for bank erosion, grade control structures, bank revetments, debris jams, depositional features, and other important features were documented within all segments and entered into the spatial component of the statewide database (the Feature Indexing Tool, FIT) via the SGA Tool (SGAT) ArcView extension, which permits implementation of the data via geographic information systems. Maps displaying this information are available for public use as well (http://maps.vermont.gov/imf/sites/ANR_SGAT_RiversDMS/jsp/launch.jsp?popup_blocked=true).

4.2 QUALITY ASSURANCE, QUALITY CONTROL, AND DATA QUALIFICATIONS

Quality assurance/quality control (QA/QC) checks of the Phase 1 data were initially conducted by the Lake Champlain Committee staff scientist and the VT Agency of Natural Resources River Management Program. Phase 1 data were originally QA'd utilizing Quality Assurance Procedures delineated in the Phase 1 Protocols in place at the time (2003) and have been screened again with automated checks implemented in the DMS since that time. The Phase 2 data were collected in compliance with the State Quality Assurance Project Plan (VT ANR 2003) and checked with Quality Assurance procedures specified in the Phase 2 Protocols (VT-RMP geoassesspro 2007). Review by both RMP personnel and the consultants conducting the assessments were cross-checked to verify integrity of the data. Documentation of the quality control checks is maintained within the SGA database (https://anrnode.anr.state.vt.us/ssl/sga/security/frmLogin.cfm). General questions about data collection methods can be answered by referencing the SGA Protocols (VT-RMP geoassesspro 2007). Specific notes regarding QA review for data collected in 2008 can be found in Appendix 5.

It should be noted that protocols are periodically revised to increase the value of the data collected. At the time of Phase 2 data collection on the downstream reaches of the Tyler Branch and The Branch in 2005, data was not collected concerning parameters for areas of straightening with attendant windrowing (rows of stone pushed up high along the banks) and for specific areas along streams with buffers of less than 25 feet; these parameters have been included with later refinements of the Protocols. Straightening appears on analysis maps for the 2005 reaches in this report, but there are not indications of whether windrowing was evident along the banks. Specific areas lacking buffers are only denoted in analysis and reach maps for reaches assessed in 2008, although these areas on the 2005 reaches are often discernable on the aerial photography accompanying reach and project identification maps.

5.0 RESULTS

The following sections summarize pertinent results of Phase I and II SGA data collection in the Tyler Branch watershed. Stressor, departure, and sensitivity maps are presented as a means to integrate the data that have been collected and show the interplay of watershed and reach-scale dynamics. These maps should assist in identifying practical restoration and protection actions that can move the river toward a healthy equilibrium (VT-RMP RCPG 2007). Single page maps are included with the text for ease of reference in regards to the text; larger maps can be found in Appendix 7.

Alterations to watershed-scale hydrologic and sediment regimes can profoundly influence reach-scale dynamics, and greater understanding of these processes is vital to increasing the effectiveness of protection and restoration efforts at a reach level (VT-RMP RCPG 2007). Section 5.1 presents an analysis of stream departure from reference conditions. Sections 5.1.1 and 5.1.2 summarize watershed-scale stressors contributing to current stream conditions, and Sections 5.1.3–5.1.6 characterize reach-scale stressors. Section 5.1.7 characterizes the hydrologic and sediment regime departures for reaches included in Phase 2 assessment within the Tyler Branch watershed. Section 5.2 presents a sensitivity analysis of these reaches, indicating the likelihood that a stream will respond to a watershed or local disturbance or stressor and an indication of the potential rate of subsequent channel evolution (VT-RMP geoassesspro 2007, Phase 2, Step 7.7; VT-RMP RCPG 2007, Section 5.2).

Data used for the analyses can be found in the appendices. Reach/segment summary statistics and channel geometry data are found in Appendix 1. Phase 1 observations, assembled at a reach scale, are summarized in Appendix 2. Reach/segment scale data from Phase 2 fieldwork are provided as summary sheets in Appendix 3. Plots of channel cross sections are found in Appendix 4. Appendix 5 includes Quality Assurance review notes. Appendix 6 is a consolidated list of projects identified in Chapter 6. Appendix 7 contains 11x17 in. maps for both select analysis (Chapter 5 maps) and all individual stream reaches assessed in 2008 (Chapter 6 maps).

5.1 DEPARTURE ANALYSIS

5.1.1 Watershed-scale hydrologic regime stressors

The hydrologic regime involves the timing, volume, and duration of flow events throughout the year and over time; as addressed in this section, the regime is characterized by the input and manipulation of water at the watershed scale. When the hydrologic regime has been significantly changed, stream channels will respond by undergoing a series of channel adjustments. Where hydrologic modifications are persistent, the impacted stream will adjust morphologically (e.g., enlarging through either downcutting or widening when stormwater peaks are consistently higher) and often result in significant changes in sediment loading and channel adjustments in downstream reaches (VT-RMP RCPG 2007).

As noted in section 3.1.3 of this report, Land use and general characteristics, the Tyler Branch is roughly 75% forested today. Historical photos of the general area accessible through the University of Vermont Landscape Change Program (http://www.uvm.edu/landscape/menu.php) indicate that the watershed was likely not as heavily deforested during the 19th century as some other areas of Vermont, particularly in the steeper terrain approaching the foothills and uplands of the Cold Hollow Mountains in the eastern portions of the watershed. Subwatersheds in the downstream portions of the watershed, however, indicate significant changes in land cover and land use that are likely contributing to channel adjustments downstream of those areas. This is particularly indicated along the Tyler Branch mainstem between West Enosburgh and East Enosburgh (reaches M05-M14; Fig. 12, next page) and The Branch near Bakersfield village (reaches T1.06-T1.12; Fig. 11). Preliminary research has indicated that "urban" land use conversions approaching 10% of a subwatershed can be sufficient to be reflected in stream dynamics (Booth and Jackson 1997), and agricultural land use strongly affects hydrology as well (Schilling and Wolter 2005). The combination of "urban" and cropland uses affects greater than 20% of the majority of the subwatersheds in these specific portions of the Tyler Branch watershed (Fig. 12).

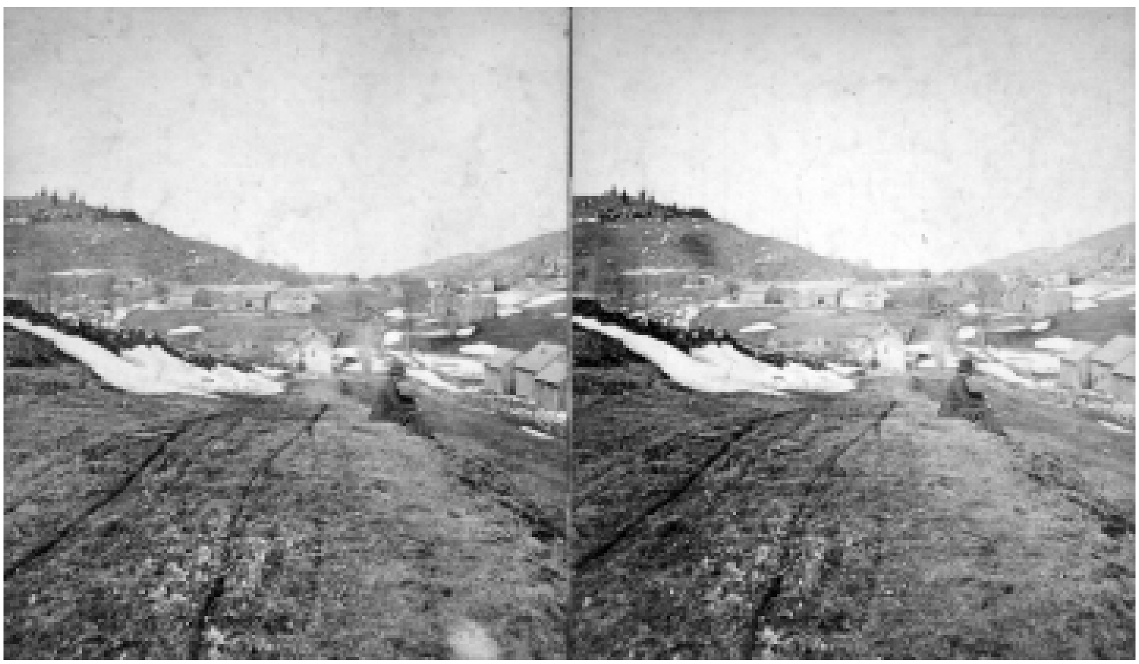


Figure 11. Stereoscopic image of the area around Bakersfield village from around 1860-1870 indicates extensive clearing in this portion of the Tyler Branch watershed (*photo credit Michaela Peabody*).

The preponderance of agricultural and settled lands in the lower elevations indicates that historical clearing was extensive in these areas, and there is a notable overlap between these cleared lands and the hydric soils and wetlands that appear in the watershed (Fig. 3). A closer look at these areas in the reach-scale maps presented in Chapter 6 reveals that many of these wetlands and hydric soils lie in close proximity to streams, and significant portions have been cleared of trees and/or drained. Analysis of soil maps in conjunction with land cover/land use maps indicates that roughly 10.3% of the hydric soils in the watershed appear to have been altered, with three-quarters of that for agricultural uses and one-quarter for "urban" uses (including residential and transportation uses).

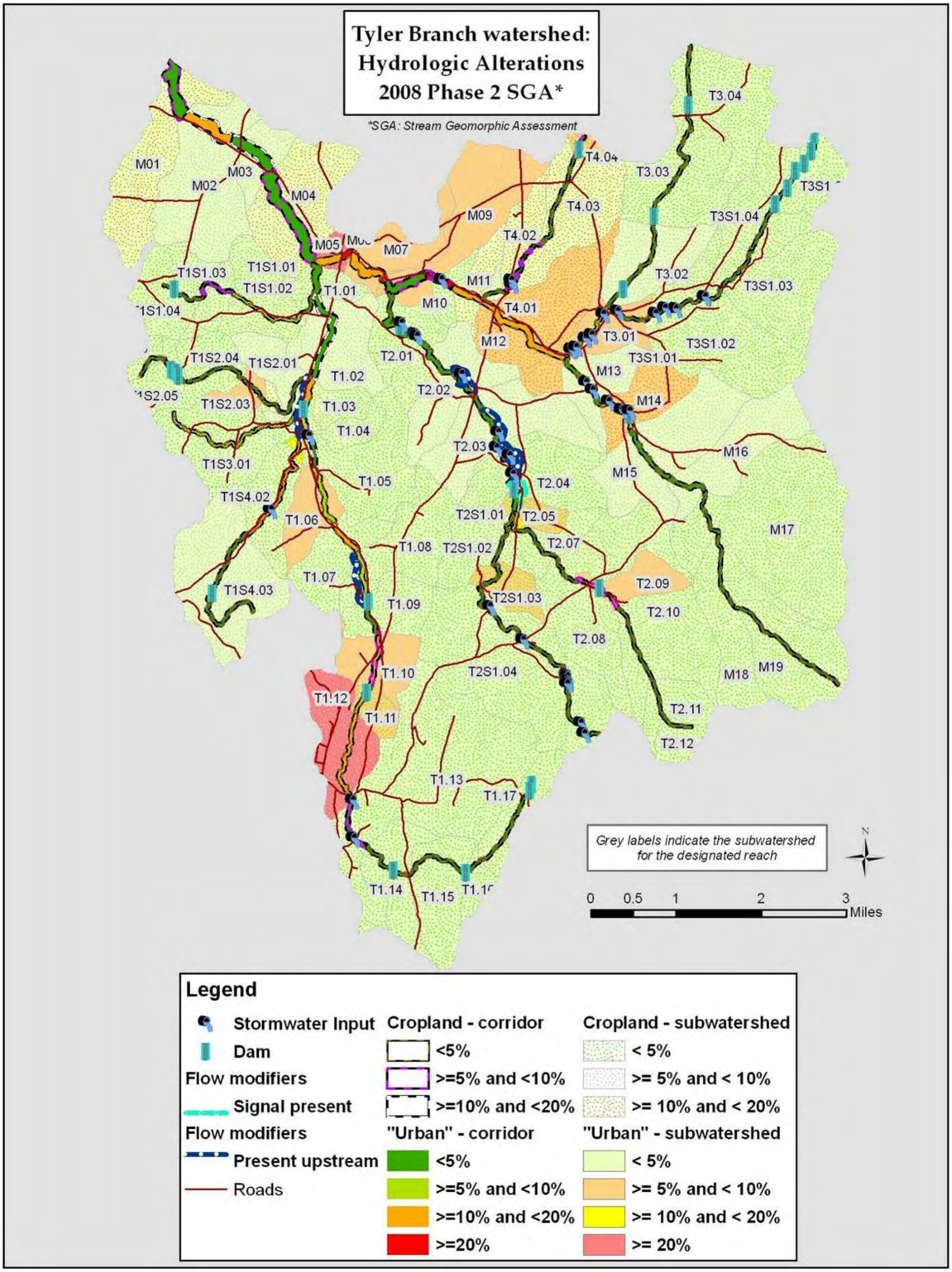


Figure 12. Watershed-scale hydrologic alterations map for the Tyler Branch watershed.

Trees play a large role in attenuating and slowing water inputs to the stream, both through the interception of water during precipitation events but also through large amounts of water that are taken up and cycled through transpiration. This can most easily be observed by the length of time that water levels remain high after a storm when leaves are off of deciduous trees (commonly 2 or 3 days after a moderate to heavy rain) in comparison with a summer storm, when water levels might recede within four to eight hours after the same type of storm. A simple experiment on a stream with well-forested buffers illustrates similar dynamics: a stick placed in a sand bar close to water level during the day will often be submerged first thing in the morning, after the period of time that trees have not been actively cycling water as rapidly as when they are exposed to sunlight. These observations help clarify the types of changes that occur in hydrologic dynamics when trees are removed from a larger landscape: water reaches the stream more quickly and in higher quantities than in areas that have trees present.

Despite the fact that the Tyler Branch watershed may not have been heavily deforested, the lack of trees and the ditching and/or draining of lands in portions of the watershed have likely increased direct inputs of water to streams as well as shortened the duration of time during which those inputs occur. These factors serve to increase stream power and degradational processes, which has likely contributed to some of the historic downcutting that has occurred on 31 of 40 reaches (43 of 73 segments) assessed in Phase 2. With the exception of areas where ledge or bedrock grade controls are frequent in the channel bed, or beaver activity is common, historic downcutting was noted in Phase 2 assessments in both 2006 and 2008 on most downstream reaches in the watershed (Fig. 13). In the large majority of these cases, this has meant a reduction in floodplain access rather than full loss of access to historical floodplains (see further discussion in Sec. 5.1.4, Sediment regime departure).

Additional watershed-scale hydrologic stressors in the Tyler Branch watershed reaches assessed during the 2008 Phase 2 assessment include historic flow regulation at dams located on the Bogue Branch and Tyler Branch mainstem, as well as likely stream diversions on the Tyler Branch mainstem near the dam at the East Bakersfield Rd./Enosburgh Mtn. Rd./Horseshoe Circle intersection (reaches M14 and M15) and at an unnamed tributary of Beaver Meadow Brook in East Enosburgh (near the T3S1.02 reach break). These factors again served to increase stream power, with heightened intensity when water was released in “pulses”. The combination of this increase in stream power and likely “sediment starving” at the dams has likely contributed to “hungry water”, a phenomenon that helps explain the significant degree of channel incision (primarily historic) observed in reaches downstream of these impacts. Dams in reaches T1.04, T1.08 and T1.11 on The Branch may also be contributing to a sediment starving and hungry water syndrome, exacerbated by land use changes in these subwatersheds (which include Bakersfield village; Fig. 12). Stream power is augmented by stormwater inputs such as road ditches, field ditches, and tile drains as well, and a relatively concentrated number of stormwater inputs were observed on Beaver Meadow Brook in Enosburgh and its tributary during 2008 Phase 2 assessments.

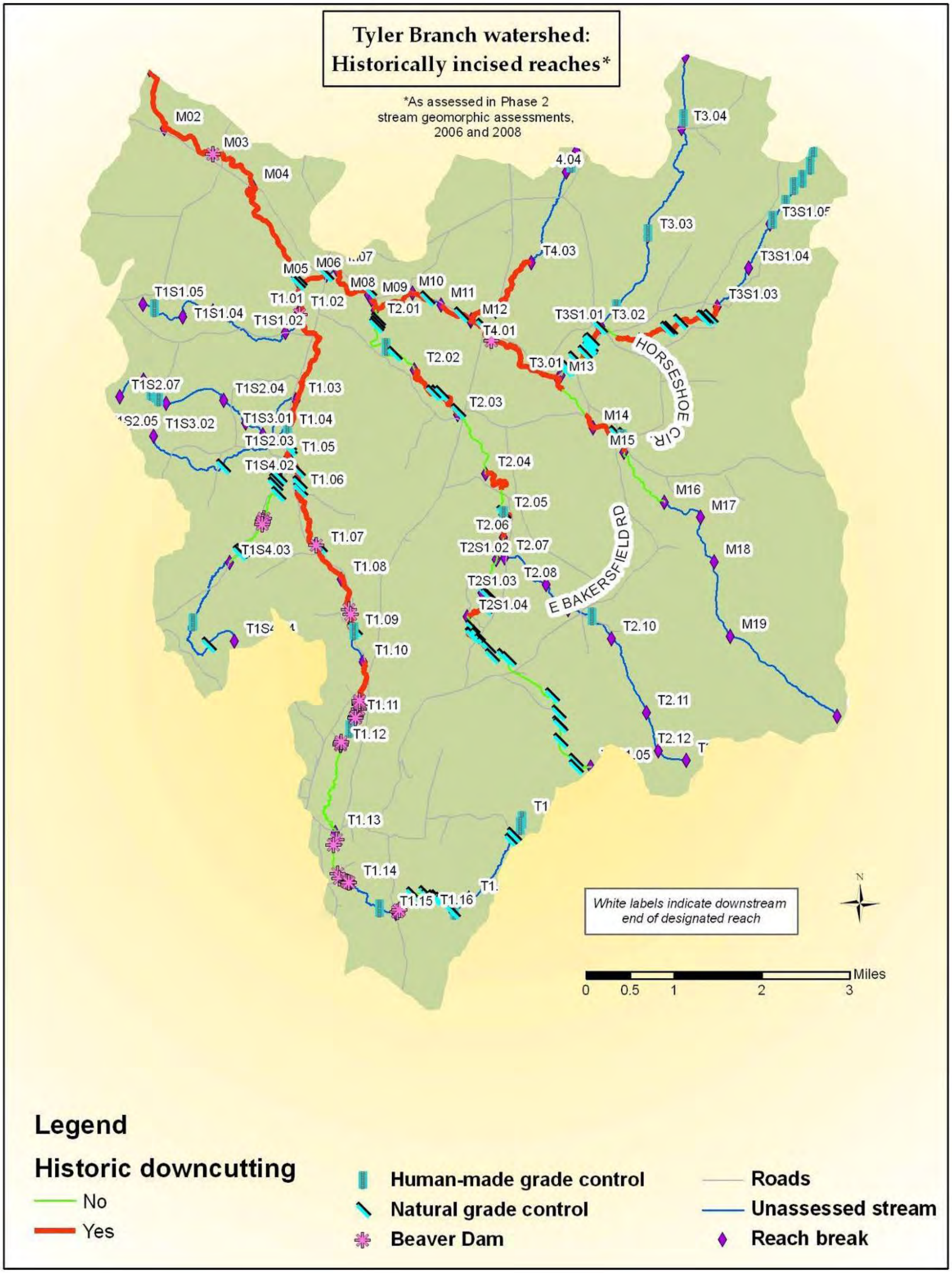


Figure 13. Phase 2 assessments in 2006 and 2008 indicated historical downcutting (incision) in numerous downstream reaches of the Tyler Branch watershed.

In 1925, the confluence of the Tyler Branch mainstem and Cold Hollow Brook was indicated a short distance upstream of an old mill pond at the East Bakersfield Rd. bridge, west of the Wright School, in what was assessed in 2008 as reach M14 (Fig. 14, smaller red rectangles). This confluence is indicated in the same place on a 1953 topographic map, but in 2008 was field-located in reach M15 (where it also appears on 1986 USGS topographic maps, Fig. 14; see also the more recent aerial photography in Fig. 32). This diversion would have meant that water did not flow through the area of an alluvial fan in reach M15.

The larger red rectangle indicates a significant wetland in a saddle between two hills just downstream of a tributary that eventually flows into Beaver Meadow Brook at East Enosburgh. The topography at the right hand turn of this stream when it reaches Horseshoe Circle, midway between East Enosburgh and the Wright School, and the fact that the wetland does not appear on 1986 USGS topographic maps (though it does appear on Vermont Significant Wetland Inventory maps), indicate possible diversion of the stream at this point. Fieldwork during 2008 indicated that this stream has cut down significantly through the erodible sideslopes approaching the tributary of Beaver Meadow Brook that it now flows into (reach T3S1.01 near the T3S1.02 reach break; Fig. 14).

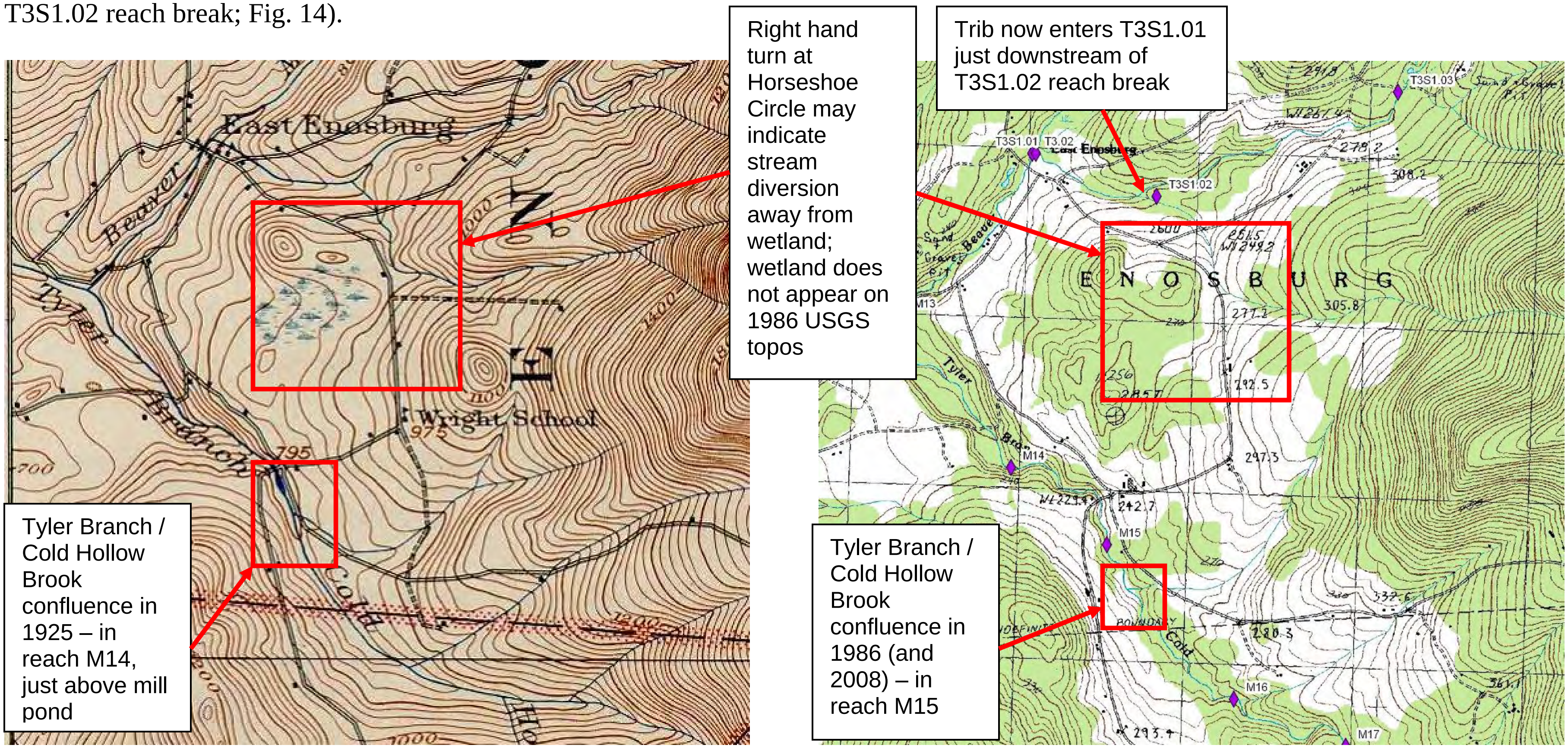


Figure 14. Topographic maps from 1925 (left) and 1986 (right) indicates possible stream diversions in eastern portions of the Tyler Branch watershed, which may have contributed to channel incision through more direct flows into the stream in a shorter period of time.

5.1.2 Watershed-scale sediment regime stressors

The following description of issues related to the sediment regime is taken from the most current version of the VT ANR River Corridor Planning Guide (VT ANR 2007):

> The sediment regime may be defined as the quantity, size, transport, sorting, and distribution of sediments. Sediment erosion and deposition patterns, unique to the equilibrium conditions of a stream reach, create habitat. Generally, these patterns provide for relatively stable bed forms and bank conditions…
>
> ….During high flows, when sediment transport typically takes place, small sediments become suspended in the water column. These wash load materials are easily transported and typically deposit under the lowest velocity conditions, which exist on floodplains and the inside of meander bendways at the recession of a flood. When these features are missing or disconnected from the active channel, wash load materials may stay in transport until the low velocity conditions are encountered….This … unequal distribution of fine sediment has a profound effect on aquatic plant and animal life. Fine-grained wash load materials typically have the highest concentrations of organic material and nutrients.
>
> Bed load is comprised of larger sediments, which move and roll along the bed of the stream during floods…. The fact that it takes greater energy or stream power to move different sized sediment particles results in the differential transport and sorting of bed materials….When these patterns are disrupted, there are direct impacts to existing aquatic habitat, and the lack of equal distribution and sorting may result in abrupt changes in depth and slope leading to vertical instability, channel evolution processes, and a host of undesirable erosion hazard and water quality impacts.

Phase 2 assessments of downstream portions of the Tyler Branch watershed in 2006 found significant aggradation in downstream reaches that did not appear to be accounted for by the amount of erosion observed in those same reaches. Two factors were posited as possibilities to explain the discrepancy:

> 1) The tributaries which were not assessed as part of this project are contributing a great deal of sediment to the system, and 2) The watershed is a naturally high bedload system, and historic dredging and gravel mining have been used to reduce the build up of sediment. Most likely it is a combination of both factors which explains the current sediment regime of the system. (MRBA (Johnson) 2006)

At a watershed scale the Tyler Branch basin appears to be a naturally high sediment load system, although the complex tapestry of geologic materials present in the watershed (see section 3.2, Geologic background, of this report), in conjunction with some prominent impediments to sediment transport continuity, appears to currently dispose the stream system to a high washload in particular. Unconsolidated geologic materials in the eastern portions of the watershed, along with shallow-to-bedrock tills in upper elevations, appear to contribute to significant sediment discharges to streams from channel avulsions, mass failures, flood chutes and bed scouring during flash floods, but dams in reach M14 on the Tyler Branch and reach T2.05 on the Bogue Branch prevent coarser sediments from continuing to move downstream (Fig.15). While there are small tributaries and other sediment sources downstream of these sites that contribute other coarse sediments to high bed loads in downstream reaches, fines from upstream discharges contribute to cumulative washloads being transported over long distances.

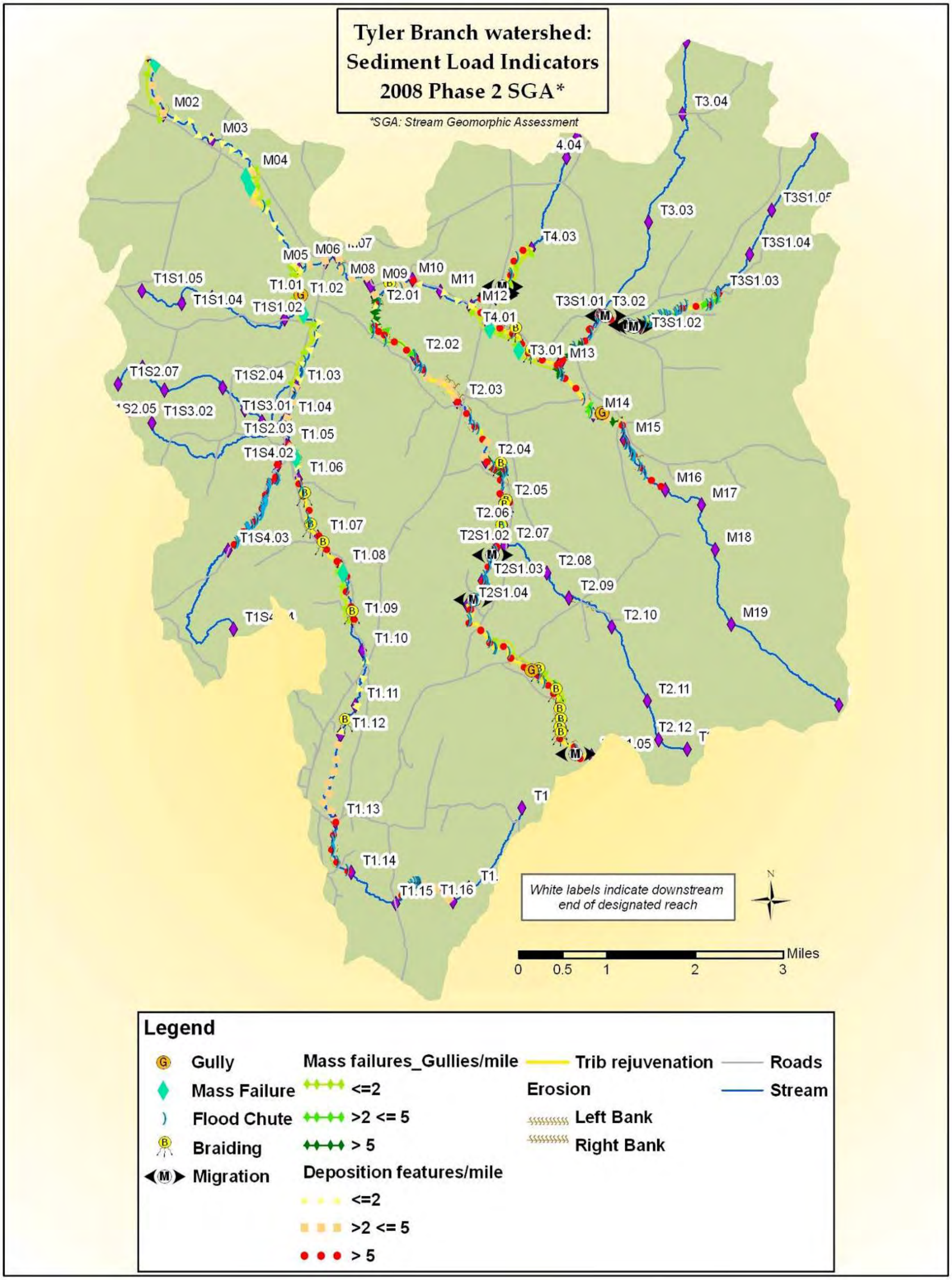


Figure 15. Watershed-scale sediment load indicators map for the Tyler branch watershed.

Coarse sediments appear to be accumulating at alluvial fan areas and similar slope gradient changes (naturally high deposition zones) above the Bogue Branch and upper Tyler Branch dams as well (M15, T2S1.02, T2S1.04). These coarse substrates increase bed resistance in all but the highest flows, predisposing streams in these areas to more lateral migration, occasionally carving new stream channels, and increasing pressure on erodible valley walls. Due to the unconsolidated materials, consequent contributions of fresh sediments to these streams send significant amounts of fines downstream while coarser sediments continue to build in current high deposition zones.

Windrowing of coarser bed materials after 1997 and 1998 floods in reaches M13, T2.04, T2S1.03 and T3S1.02 appears to have also disrupted coarse sediment transfer to downstream reaches, as well as contributing to planebed formation that has increased stream power and removed features that would store, sort and distribute sediments more equally under reference conditions. Removal of woody debris and sediments appears to be ongoing in reach M13, and gravel removal and bar scalping were evident at numerous points in reach T2.03 during 2008 fieldwork. These factors effectively contribute to progressive sediment “fining” in downstream reaches, removing coarser sediments and leaving a relatively high proportion of fines that are likely to drop out only under low velocity conditions. Possibly due to the number of floods within the last decade, there was little evidence of heavy increases in deposition at any constrictions assessed during Phase 2, although windrowing in reaches T2S1.03 and T3S1.02 appeared related to replacement of bridges in those areas following 1997 or 1998 flood damage. These areas may have had previous deposition (indicating disruptions to sediment transport continuity) that was removed or relocated in the windrowing and bridge replacement process (for further discussion see Sec 5.1.3b, Channel depth modifiers).

Downstream of the dams, tributary rejuvenation was noted on both Bogue Branch and the Tyler mainstem (sediments are recruited from tributaries when the mainstem has incised and the bed elevation of the tributary begins to drop to meet the lower elevation of the receiving stream). Some of this was likely triggered by recent stormwater inputs (such as field and road ditches) in the tributaries themselves. Regardless, these sediments augment moderate bank erosion (particularly on lower elevation reaches lacking woody buffers) and mass failures and gullies along steep to extremely steep valley walls to add further sediments to these processes downstream in the watershed (Fig 15).

Ancient lake sediments are more prominent in western portions of the watershed, and a high degree of beaver activity in this portion of the watershed appears to coincide with a preponderance of these deposits along The Branch and Beaver Meadow Brook in Bakersfield, which flows into The Branch near the Bakersfield/ Enosburgh town line (Fig. 6). Beaver dams throughout the watershed appeared heavily impacted by summer 2008 flash flooding: several areas of broken dams were observed, with only one intact dam assessed in the 2008 Phase 2 reaches (downstream end of reach T1.15). Despite the ephemeral nature of these dams, the combination of impoundments and low slope gradients in reaches T1S4.02, T1.13, and the downstream portions of reach T1.15 serves to slow the transfer of both sediments and water to downstream reaches. Due to the types of soils present, sediments that do get moved are dominated by fines. Significant aggradation noted in downstream portions of The Branch (reaches T1.06-T1.08 in particular; Fig. 15) appears to be largely composed of fine materials and likely related to a combination of “coarse sediment starving” at dams, transport of fine-grained washload materials, and channel adjustment processes dating to 1997 and 1998 flooding in the watershed. “Sediment slugs” may still be working their way through the watershed on these low gradient streams located downstream of significant beaver activity; the 2006 Phase 2 assessment noted gravel-dominated substrates in most of these reaches. Although gully formation in reach T1.15 of The Branch was noted for heavy contributions of sediment in 2008 field work, these impacts were relatively recent and considerable amounts of coarse woody debris present in the channel were retaining large amounts of the sediment discharges to the stream. The intact beaver dam at the base of the reach would also prevent much of this sediment from immediately moving downstream.

5.1.3 Reach-scale stressors

Watershed-scale stressors form a hierarchical pretext for understanding the timing and degree to which reach-scale modifications are contributing to field-observed channel adjustments (VT ANR 2007). Modifications to the valley, floodplain, and channel, as well as boundary (bank and bed) conditions, can change the hydraulic geometry, and thus change the way sediment is transported, sorted, and distributed (Table 5). Phase 1 and Phase 2 assessments provide semiquantitative data-sets for examining stressors and their effects on sediment regime when channel hydraulic geometry is modified.

Table 5. Reach level stressors: relationship of energy grade and boundary conditions in sediment transport regime (VT-RMP-RCPG 2007).

		Sediment Transport Increases	**Sediment Transport Decreases**
	Stream power as a function of:	**Stressors that lead to an increase in power**	**Stressors that lead to a decrease in power**
Energy Grade	**Slope**	• Channel straightening, • River corridor encroachments, • Localized reduction of sediment supply below grade controls or channel constrictions	• Upstream of dams, weirs, • Upstream of channel/floodplain constrictions, such as bridges and culverts
	Depth	• Dredging and berming, • Localized flow increases below stormwater and other outfalls	• Gravel mining, bar scalping, • Localized increases of sediment supply occurring at confluences and backwater areas
Boundary Conditions	**Resistance to power by the:**	**Stressors that lead to a decrease in resistance**	**Stressors that lead to an increase in resistance**
	Channel bed	Snagging, dredging, windrowing	Grade controls and bed armoring
	Stream bank and riparian	Removal of bank and riparian vegetation (influences sediment supply more directly than transport processes)	Bank armoring (influences sediment supply more directly than transport processes)

Channel Slope and Depth Modifier Maps (Sections 5.1.4 and 5.1.5, respectively) can be used to determine whether stream power has been significantly increased or decreased. A Channel Boundary and Riparian Modifiers Map (Section 5.1.6) can help explain whether the resistance to stream power has been increased or decreased.

5.1.3a Channel slope modifiers

Analysis of channel slope modifiers in the Tyler Branch watershed indicates that channel straightening has not been extensive in the watershed but has played an important role in stream dynamics along the Bogue Branch (T2.01-T2.05), The Branch downstream of Bakersfield village (T1.01- T1.08), and the Tyler Branch and its tributaries near Gilbert’s Tannery and East Enosburgh villages (M11, M13-M14, T4.01-T4.02, T3.01, T3S1.01-T3S1.02; Fig. 16). Channel straightening in limited areas occurred historically through direct channel manipulation to supply mills on the Bogue Branch and Tyler Branch (reaches T2.05 and M14), but has occurred more extensively through a combination of incremental impacts including: road and development encroachments; structural measures such as riprap and bank toe stabilization; less direct maintenance of the channel “in its place” through field cultivation and ditching; and remediation of flood damage (particularly after 1997 and 1998 floods) through windrowing of stream sediments, removal of debris jams, and channel “clean-outs” in the areas of bridges damaged in the floods and subsequently repaired or replaced.

In areas with erodible bed materials, channel straightening can exacerbate a loss of floodplain access due to increased downcutting. Portions of the Bogue Branch, where field cultivation did not obscure these impacts, illustrated successive losses of floodplain over time through multiple abandoned terraces observed in broader portions of the valley. Bed downcutting can play a significant role in enhancing sediment transport capacity as a result of the increased slope and depth at flood stage, but has been somewhat limited in the watershed overall. Due to coarse substrates in both the bed and banks of upstream reaches in the eastern portions of the Tyler Branch watershed, many of the impacts of heightened stream power are currently transferred to the downstream reaches of the Bogue Branch and Tyler Branch in particular, where fine sediments are more common in the stream bed and banks. Even in these areas, however, there are a number of ledge grade controls and waterfalls interspersed throughout, limiting channel incision and thus increasing erosive power on banks and valley walls in flood flows (an impact that is exacerbated when erodible soils are lacking woody vegetated buffers). Contributions of fine sediments from these areas are contributing to washloads that normally drop out on floodplains and meander bends, which have been diminished in extent by the type of successive floodplain loss observed on Bogue Branch.

Due to the combination of coarse substrates and frequent, intermittent grade controls in eastern portions of the Tyler Branch watershed, the primary slope modification that appears to occur as the stream seeks equilibrium occurs through meander development. This decreases slope as the stream moves across slope gradients rather than dropping more directly. Stream type departures from an E-type to a C-type stream in reach T2.04 of Bogue Branch were in large part related to a loss of stream sinuosity (as well as slightly steeper slopes imposed by channel straightening), and sediment storage in point

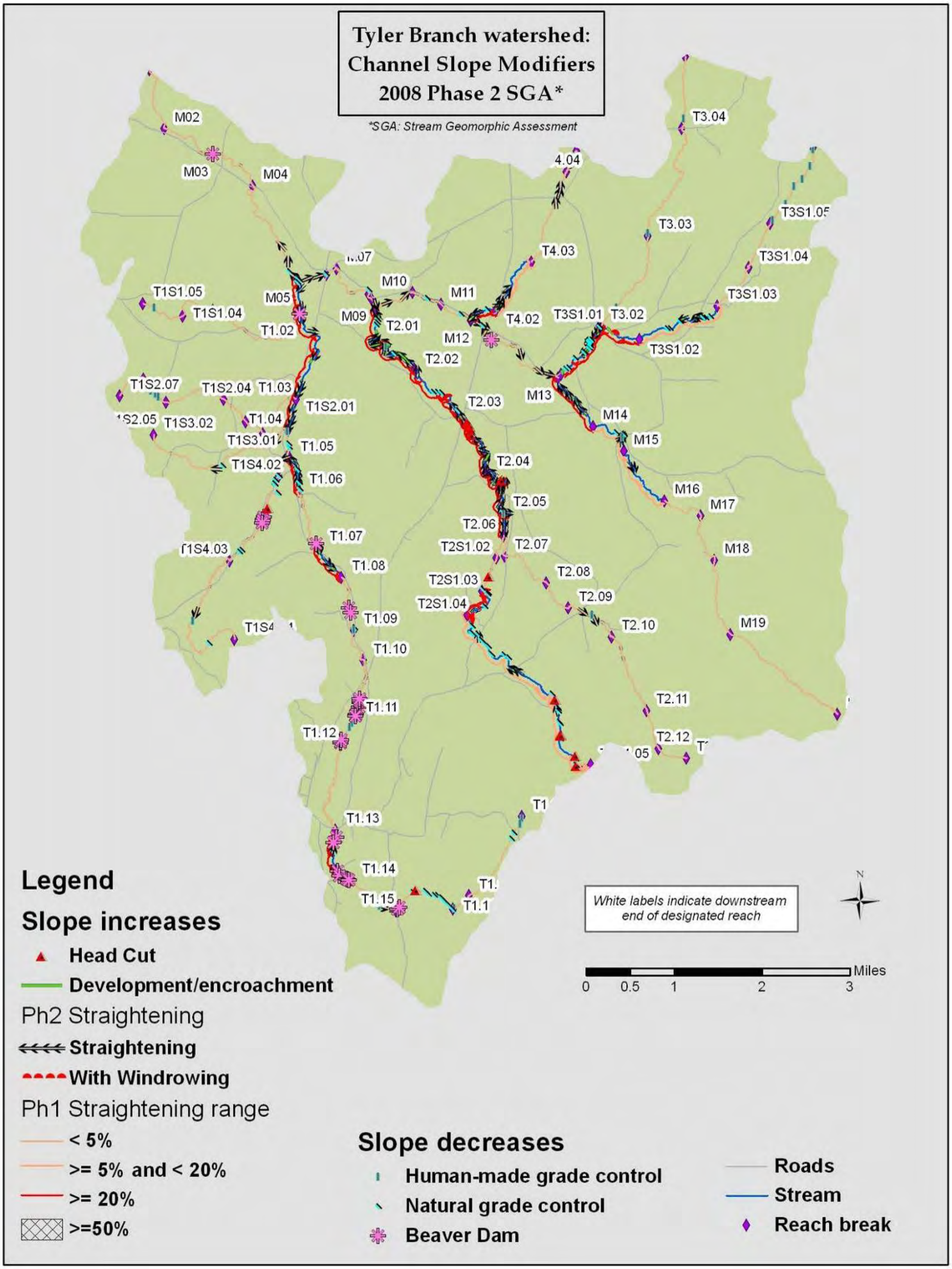


Figure 16. Reach-scale stressors: Channel slope modifiers map for the Tyler Branch watershed.

bars now appears to be occurring as the channel tries to evolve back toward a narrower, more meandering stream channel in this area.

In areas with well established woody buffers, old channels were observed to the full extent of valley width, indicating that channel avulsions could move the stream dramatically to a new location in a flood event. In this pattern, the stream might remain in the new location for decades before moving to another location in a flood. Trees in these areas not only stabilize soils, but serve a direct physical role in diffusing stream power in floods as well as contributing large woody debris that was observed playing an important role in retaining and slowing the movement of sediments and allowing redevelopment of (or development of new) meanders.

In western portions of the Tyler Branch watershed (The Branch and Beaver Meadow in Bakersfield), fine sediments are much more common and beaver activity appears to play a large role in slope reductions and consequent attenuation of stream power and sediment loads (Fig. 16). These fines are highly erodible, however, and areas where the stream channel has been straightened (particularly at stream crossings) have contributed washload sediments to the stream system when slopes have been thus increased. These impacts are heightened when shrubby vegetation that stabilizes the banks in these areas is impacted or removed (observed in several pastures). A relatively low number of channel encroachments in areas assessed in 2008 clearly helps accommodate the beaver activity and meandering pattern of these streams that play an important role in reducing stream power and erosion.

5.1.3b Channel depth modifiers

Phase 1 and 2 data collection in the Tyler Branch watershed indicated relatively limited amounts of road or berm encroachment, concentrated downstream of Bakersfield village (T1.05-T1.10), along Bogue Branch (T2.01and T2.04), and along the tributaries of the Tyler Branch (T3.01, T3S1.01-T3S1.02, T4.01-T4.02; Fig. 17). Berms and elevated roads within the river corridor increase the depth of flood flows, and thus also increase stream power. Stormwater inputs such as tile drains, road and field ditches can contribute to these effects as well, and a concentration of these in East Enosburgh, along with historic stream diversions in conjunction with ledge grade controls and coarse, erosion resistant bed substrates has likely elevated flow impacts on the Tyler Branch mainstem. Localized depth increases are often experienced in high flows in the vicinity of bridges and similar channel constrictions, which are widely dispersed in the watershed.

Fieldwork in 2008 also indicated that the close proximity of hydric soils and wetlands to the stream channel throughout the watershed played an unusual, significant role in flash flooding during summer 2008. Flow depths were elevated by rapid discharges when soils already saturated during one of the wettest summers on record were further inundated with at least one intense rainstorm. The resulting gullies and elevated erosion in some of these areas highlighted the important role these hydric soils and wetlands normally play (when not already saturated) in attenuating high precipitation inputs and slowing the rate at which this water enters stream channels. It is less clear what type of role these dynamics may have played in previous flooding in the watershed during the 1990s (see Sec. 3.4.2, Flood history).

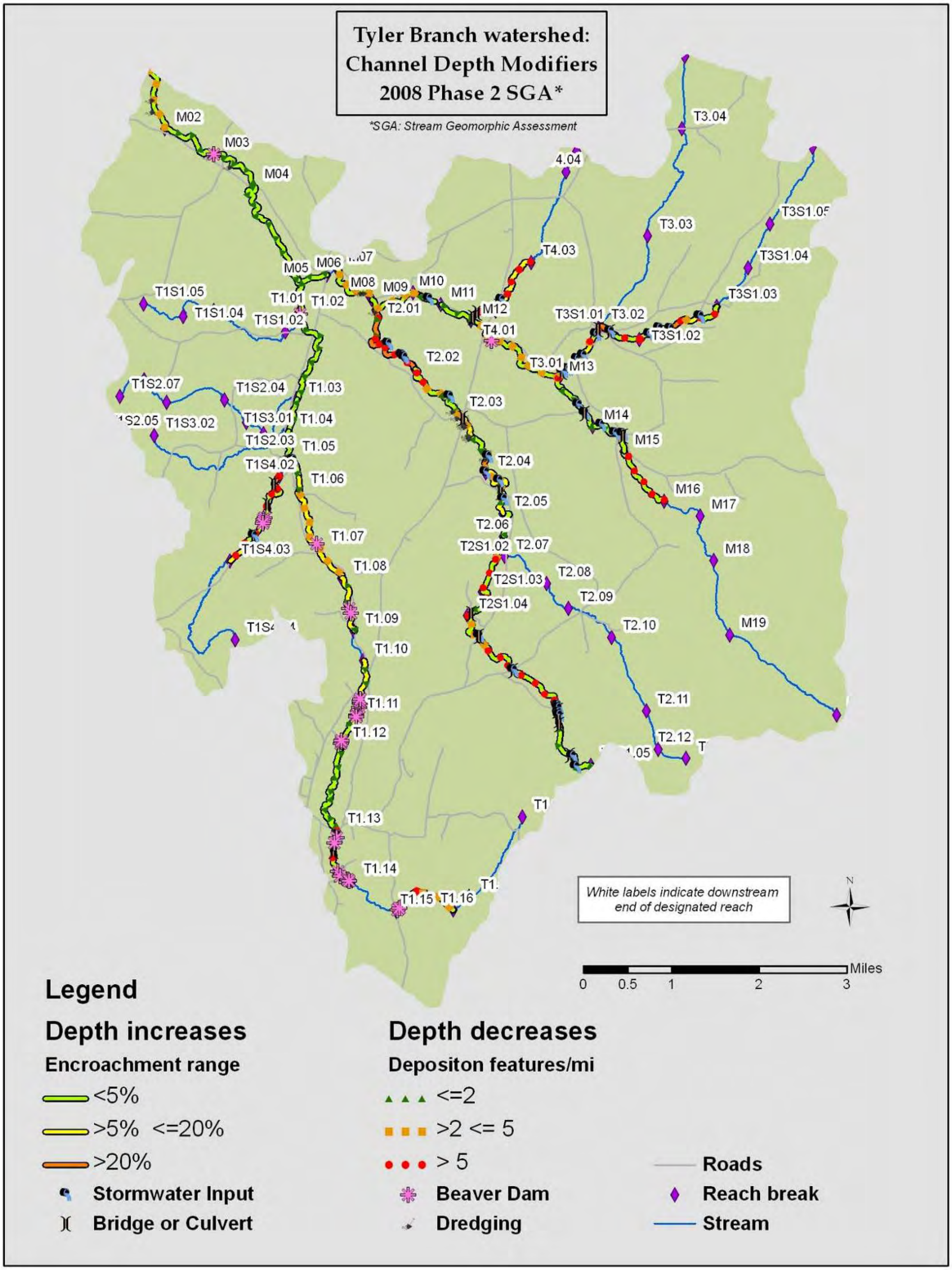


Figure 17. Reach-scale stressors: Channel depth modifiers map for the Tyler Branch watershed.

Significant deposition, particularly delta and backwater deposits, create the potential for more shallow depths during moderate flows due to the sediment build-up and the wider channel that results from the backwater conditions. Stream power is often reduced in these areas, leading to further deposition. Moderate to heavy deposition was noted in 31 of 45 stream segments assessed in the eastern portions of the Tyler Branch watershed (Fig. 17) and contributes heavily to the meander development and channel avulsions that play a prominent role in the characteristic channel evolution of these streams. Deposits of finer materials play a similar role in meander development in the low gradient areas of the western portions of the watershed, and concentrations of depositional features were often associated with beaver activities in these areas. Large woody debris also plays a critical role in both fine and coarse sediment storage and transport dynamics in higher gradient portions of the watershed, and was particularly in evidence in this role in reaches T.15 of The Branch, T3S1.02 in East Enosburgh, and the upstream portions of reach T2S1.04 on Ross Brook during 2008 assessments.

Downstream reaches on both The Branch and Tyler Branch indicate fewer depositional features on a per-mile basis than the upstream portions of the watershed (Fig. 17). Assessments on these reaches in 2006 noted that, "The dominant sediment regime for the watershed is aggradation. A tremendous amount of excess sediment was observed throughout as seen by enlarged point, side, mid-channel and diagonal bars. Multiple steep riffles were also observed" (MRBA (Johnson) 2007). It appears these deposits are likely accruing at areas of decreased stream velocity, building upon themselves, and given the series of floods in the 1990s may represent sediment "slugs" moving through the watershed in periodic high and moderate flows.

Gravel removal, windrowing and bar scalping was observed in reaches T2.03, T2.04 and T2S1.03 on Bogue Branch, M13 on Tyler Branch, and Tyler Branch tributary reaches T4.01, T3.01, T3S1.01 and T3S1.02. This practice contributes to the potential for more shallow depths due to the over-widened channel that typically results from dredging, gravel mining, and bar scalping. Removals in T2.03 and M13 appear to be ongoing, and were being stockpiled for future use (Fig. 18); removals in the other areas were primarily windrowing following flood impacts in the 1990s. Stream dynamics related to this practice are complex, but it does appear that the low velocity conditions encountered in many of these areas were contributing to further accumulation of sediments (Fig. 19). Ongoing removal of these sediments, in combination with "sediment starving" at dams on Bogue Branch and Tyler Branch, may be contributing to a progressive "fining" of sediments being transported downstream (see further discussion in Sec 5.1.2, Watershed-scale sediment regime stressors).

Figure 18. Sediment windrowing (left) and small-scale stockpiling (right) in reach M13.

Figure 19. More sediments often drop out when low velocity conditions are encountered in widened channels near locations of gravel removal, as seen upstream (right) of this stockpile in reach T2.03.

5.1.3c Boundary condition and riparian modifiers

Stream boundaries include bed and banks, and are also affected by the state of buffer vegetation in the riparian corridor. Root systems from woody vegetation (and, to a lesser extent, herbaceous vegetation) help bind stream bank soils.

Nearly all reaches assessed in Phase 2 assessments during 2006 and 2008 in the Tyler Branch watershed were noted with coarse bed materials (the only exceptions were segments T1.13A and C on The Branch and segment T1S4.02B on Beaver Meadow Brook in Bakersfield). There are bedrock grade controls interspersed throughout the watershed as well, and bed degradation has thus been limited throughout the watershed. Under these conditions, it would be expected that erosive pressures would be increased on the banks in high flows. Out of 73 stream segments assessed in 40 reaches during 2006 and 2008, only 3 segments in two reaches were noted with high levels of erosion (>20% of either bank eroding; Table 6). An additional 20 segments in 16 reaches showed moderate levels of erosion on at least one bank (5-20% of the banks eroding; Table 6). Higher levels of erosion were concentrated along Bogue Branch (T2.01 – T2S1.03), Tyler Branch downstream of the dam in reach M14, and Beaver Meadow Brook and its tributary in East Enosburgh (Fig. 20; Table 6).

Table 6. Tyler Branch watershed segments noted with moderate to high levels of erosion during 2006 and 2008 Phase 2 assessments.

	Left bank erosion		Right bank erosion	
Reach	>20%	>5% <=20%	>20%	>5% <=20%
The Branch				
T1.05				T1.05A
T1.13		T1.13B		T1.13B
Tyler Branch				
M13		M13C		M13C
M14		M14A		
Bogue Branch				
T2.01				T2.01A
				T2.01C
T2.02		T2.02C	T2.02C	T2.02A
T2.03		T2.03A		T2.03A
				T2.03C
T2.04				T2.04B
T2.05				T2.05
T2S1.02		T2S1.02B		
T2S1.03		T2S1.03C		T2S1.03C
Ross Brook				
T2S1.04		T2S1.04D		T2S1.04A
Beaver Meadow Brook and trib (East Enosburgh)				
T3.01		T3.01C		
T3S1.01	T3S1.01B			T3S1.01A
				T3S1.01B
T3S1.02		T3S1.02A	T3S1.02B	T3S1.02D
Trib to Tyler Branch (Gilbert's Tannery)				
T4.02		T4.02		

Bank revetments are concentrated in these same portions of the watershed as well, with moderate (5-20% of the banks armored on one side or the other) to high (>20% armored) levels of revetments particularly noticeable on Bogue Branch downstream of the dam in reach T2.05, The Branch downstream of Bakersfield village, Tyler Branch downstream of the dam in reach M14, and Beaver Meadow Brook and its tributary in East Enosburgh (Fig. 20). Although bank armoring represents increased boundary resistance, it requires maintenance and usually indicates where banks are prone to failure or erosion if not armored.

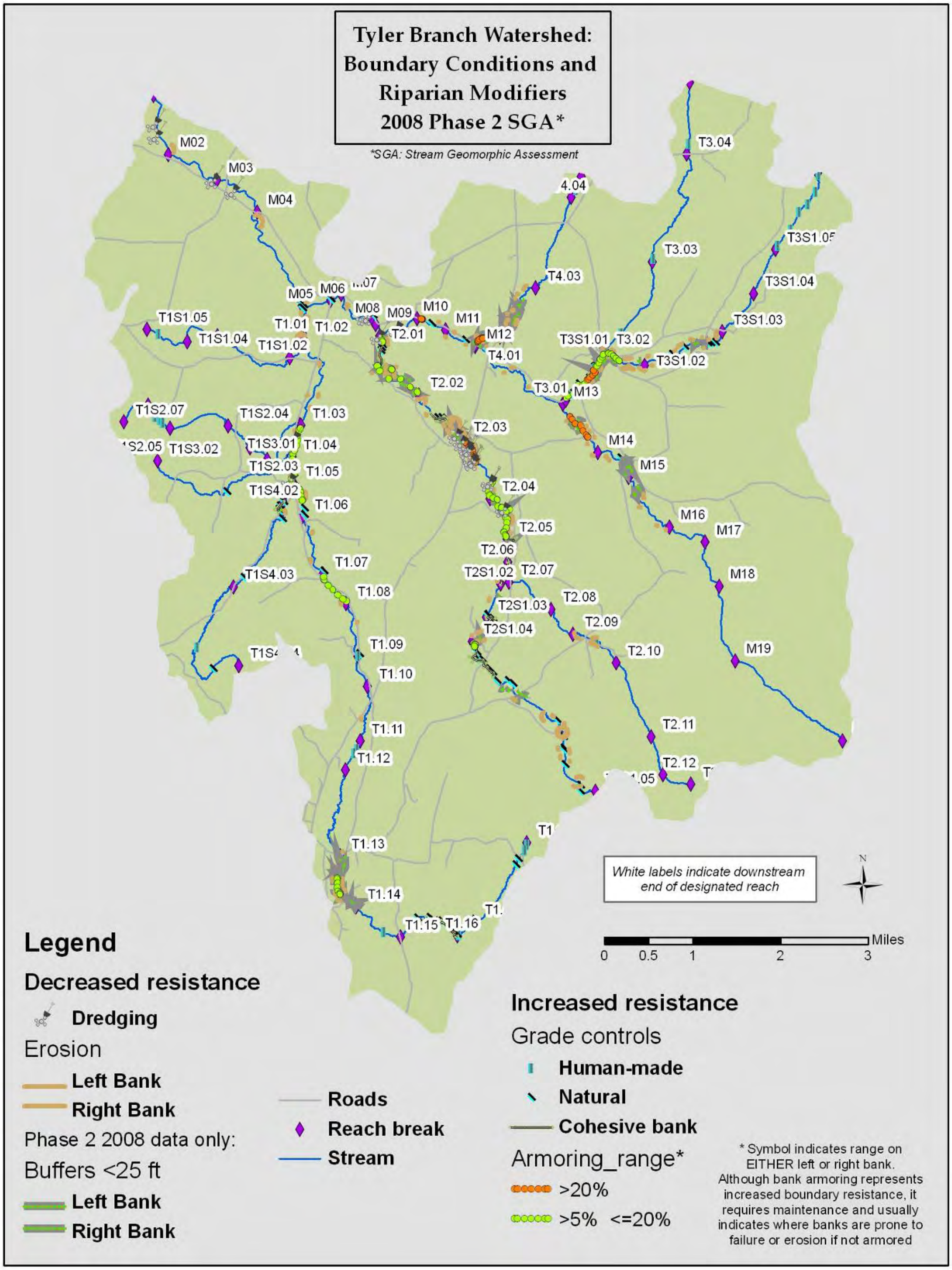


Figure 20. Reach-scale stressors: Boundary condition and riparian modifiers map for the Tyler Branch watershed.

Although data collection under protocols in place in 2006 did not denote the locations of areas with vegetated buffers of less than 25 feet, there is a clear overlap between elevated levels of erosion and bank armoring and areas lacking buffers along the reaches assessed in 2008 (Fig. 20). In addition, the propensity of streams to avulse and undergo rapid lateral migrations, in eastern portions of the watershed in particular, reinforce the importance of wooded buffers for diffusing stream power, mitigating flood damage, and stabilizing soils outside of the current stream channel as well. The flash flooding that occurred in the watershed in 2008 indicated a number of places, where channels had relocated, that would have lost a great deal more soil if the area had not been wooded. The trees that toppled into the streams in these areas were doing a great deal of work in slowing the movement of sediments downstream as well.

5.1.4 Sediment regime departure, constraints to sediment transport, and attenuation

Within a reach, the principals of stream equilibrium dictate that stream power and sediment will tend to distribute evenly over time (Leopold 1994). Changes or modifications to watershed inputs and hydraulic geometry create disequilibrium in the balance of these forces and lead to an uneven distribution of power and sediment (Fig. 21). Whether a project works with or against the physical processes at play in a watershed is primarily determined by examining the source, volumes, and attenuation of flood flows and sediment loads from one reach to the next within the stream network. If increasing loads are transported through the network to a sensitive reach, where conflicts with human investments are creating a management expectation, little success can be expected unless the restoration design accommodates the increased load or finds a way to attenuate the loads upstream (VT-RMP RCPG 2007).

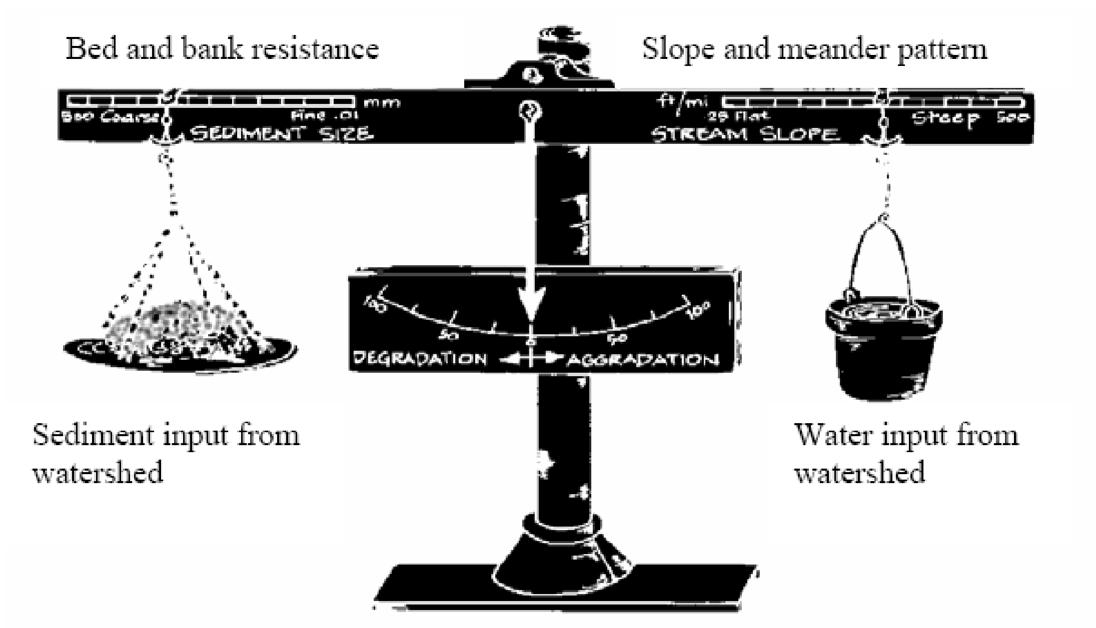


Figure 21. The channel balance indicates how changes in watershed inputs influence channel adjustment processes (Lane 1955).

Phase 1 designates a “reference type” for all reaches, and 35 of the 40 reaches included in Phase 2 assessments in the Tyler Branch watershed are considered C-type streams under reference conditions (based primarily on natural valley confinement and valley slope; see Section 3.3). Reaches T1.13 on The Branch and T2.04 on Bogue Branch are E-type streams by reference, while Ross Brook reach T2S1.04 and Tyler Branch tributary reach T4.01 are B-type streams. The Branch reach T1.15 is the only A-type stream by reference that has been included in the assessments.

The C-type stream is typically found in unconfined valleys, displays a meandering nature, and uses floodplains for sediment storage and dissipation of stream power. E-type streams display similar characteristics but also have a very low width to depth ratio and a more sinuous nature, generally flowing through fine-grained alluvial materials in very low gradient settings. Under reference conditions, the sediment regime of the Tyler Branch watershed would be one in which the large majority of assessed reaches would provide for coarse particle equilibrium (in = out: i.e., stream power, which is produced as a result of channel gradient and hydraulic radius, is balanced by the sediment load, sediment size, and channel boundary resistance) and fine sediment deposition at annual flood flows, largely on the floodplains (“Coarse Equilibrium and Fine Deposition” sediment regime, Table 7; VT-RMP RCPG 2007, pp. 34–36).

The two B-type and one A-type streams included in 2008 assessments are higher gradient streams in more confined valley settings and would typically demonstrate a Transport sediment regime, contributing minor amounts of sediments of various sizes to downstream reaches under reference conditions.

Table 7. Pertinent Phase 1 reference sediment regime parameters for Tyler Branch watershed reaches included in 2006 and 2008 Phase 2 assessments.

Sediment regime	Natural valley types	Pertinent reference stream types	Applicable Tyler Branch watershed reaches
Transport	NC, SC, NW Valley slope >2%	A3, B3, B4	T1.15, T2S1.04, T4.01
Coarse equilibrium (in = out) & fine deposition	NW, BD, VB Valley slope <2%	C3, C4, E4	M13, M14, M15, T1.13, T1S4.02, T2.01, T2.02, T2.03, T2.04, T2.05, T2S1.01, T2S1.02, T2S1.03, T2S1.04, T3.01, T3S1.01, T3S1.02, T4.02

NC, Narrowly confined; SC, Semiconfined; NW,Narrow; BD, Broad; VB, Very Broad

Phase 2 sediment regimes (which help identify departures from reference conditions) are determined based on a number of parameters measured in rapid field assessments (VT-RMP RCPG 2007, pp. 34–36), as summarized in Table 8. These include field signs of active adjustment processes indicating that streams are in a state of disequilibrium, including a likely stage of channel evolution.

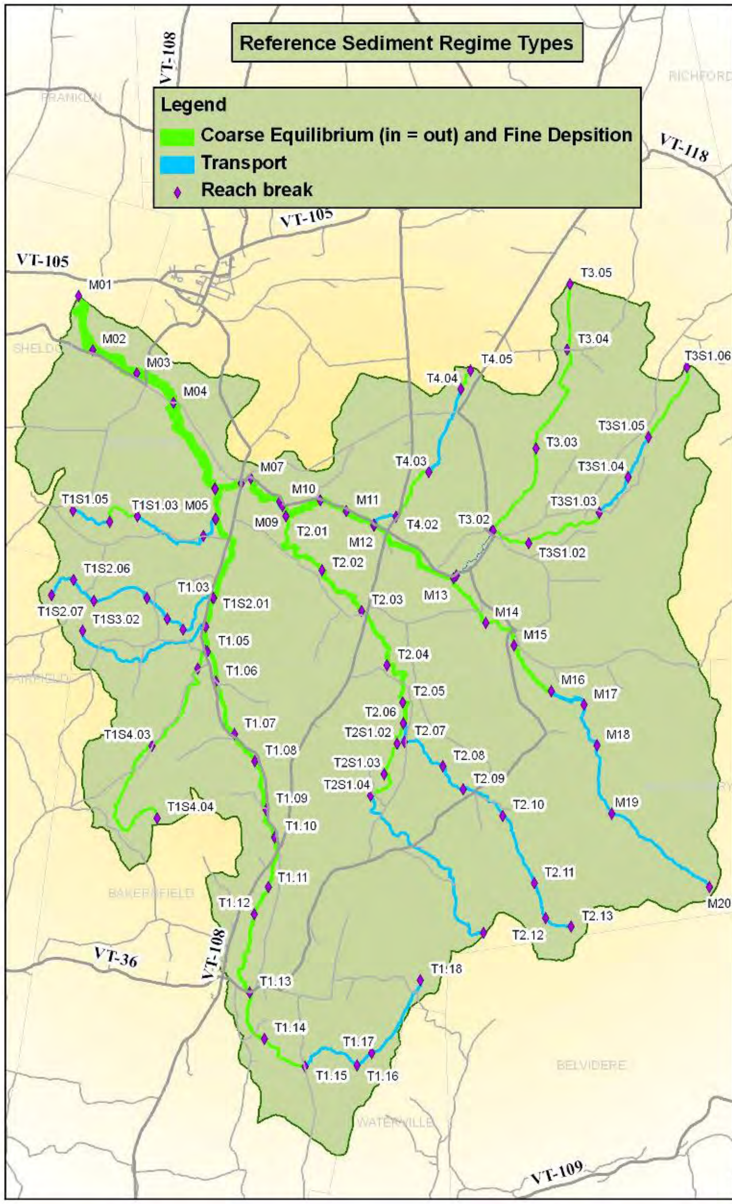
Table 8. Pertinent data for characterizing Tyler Branch watershed corridor planning area existing sediment regime using Phase 2 data (VT ANR RCPG 2007).

<table>
<tr><td rowspan="2">Transport</td><td rowspan="4">Incision <1.3</td><td colspan="3">Valley type = NC, SC, or bedrock gorge</td></tr>
<tr><td rowspan="2">Valley type = NW</td><td colspan="2">Stream type = A, B, or F</td></tr>
<tr><td rowspan="2">Coarse equilibrium & fine deposition</td><td colspan="2">Stream type = Bc, C, or E</td></tr>
<tr><td colspan="3">Valley type = BD or VB</td></tr>
<tr><td>Confined source & transport</td><td rowspan="4">Incision ≥1.3</td><td colspan="3">Valley type = NC or SC</td></tr>
<tr><td>Unconfined source & transport</td><td rowspan="3">Valley type = NW, BD, VB</td><td rowspan="2">Channel evolution stage = I/II/III/V</td><td>Bank armoring and straightening ≥50%</td></tr>
<tr><td rowspan="2">Fine source & transport, coarse deposition</td><td>Bank armoring or straightening <50%</td></tr>
<tr><td colspan="2">Channel evolution stage = IV</td></tr>
</table>

Sediment regime departure

Phase 2 assessments indicated that, in contrast to 47 Phase 1 reaches that would function as Coarse Equilibrium and Fine Deposition (CEFD) areas under reference conditions, only 18 segments (smaller portions of reaches) in 40 Phase 2 reaches currently function with CEFD sediment regimes in the Tyler Branch watershed. Most currently function as Transport streams, with the large majority having been converted to “Fine Source & Transport and Coarse Deposition” sediment regimes (Fig. 22). These alterations appear to be largely driven by changes in hydrology, with patterns of sediment transport and storage strongly affected by (but also affecting) increased stream power.

Roughly 10% of the wetland areas and hydric soils in the Tyler Branch watershed are no longer forested due to both “urban” and agricultural land use conversion (and/or are open wetlands; see Sec. 3.1.3, Land use history), and a large proportion of these “altered wetlands” lie in close proximity to the streams in this watershed. Although it is difficult to know for certain how these contributed to flood impacts in the 1990s, field observations in 2008 indicated that already-saturated soils contributed large amounts of water directly to streams when further inundated by at least one intense storm during summer 2008 (see Sec. 3.4.2, Flood history). There are also significant breaks in coarse sediment continuity at dams in upstream portions of the watershed. The combination of “sediment starving” and increased stream power creates localized occurrences of "hungry water", which tends to recruit the most erodible sediments at hand (typically containing a large proportion of fines).



Tyler Branch watershed Sediment Regime Departure

The map on the left is based primarily on the relationship of the river to its valley type and valley slope. This Phase 1 assessment identified 47 reaches within the Tyler Branch watershed with "Coarse equilibrium and Fine Deposition" sediment regimes. These reference type streams utilize access to their floodplains as a primary means to store sediment and nutrients within the watershed. Tributary reaches and upstream mainstem reaches in the Project area were identifed with Transport sediment regimes under reference conditions.

Due to changes in hydrology and sediment storage and transport within the watershed, exisiting stream types and dynamics identified in Phase 2 rapid field assessments (map at right) indicate that only 18 segments (portions of reaches) within the Tyler Branch watershed assessment area retain "Coarse equilibrium and Fine Deposition" sediment regimes; most have been converted to some type of transport regime. This means that most sediment entering the stream is either being transported through without being deposited, or is being dropped out when the load reaches a point the stream cannot carry (or at channel constrictions such as old abutments and dam remains).

Although important ledge grade controls have limited downcutting in both downstream and upstream portions of the watershed, high flows have combined with "sediment starving" at dams to increase stream power and fine sediment transport through the watershed.

Due to coarse substrates present in many of the upstream portions of the watershed in particular, stream power is frequently diffused through lateral migration and extensive meanders, with old channel remains visible to the extent of both valley walls in many of the narrrower valleys. Corridor protection to allow for full development of these patterns can do much to maintain the role of vital attenuation assets in the Tyler Branch watershed and reduce stream power and flood impacts.

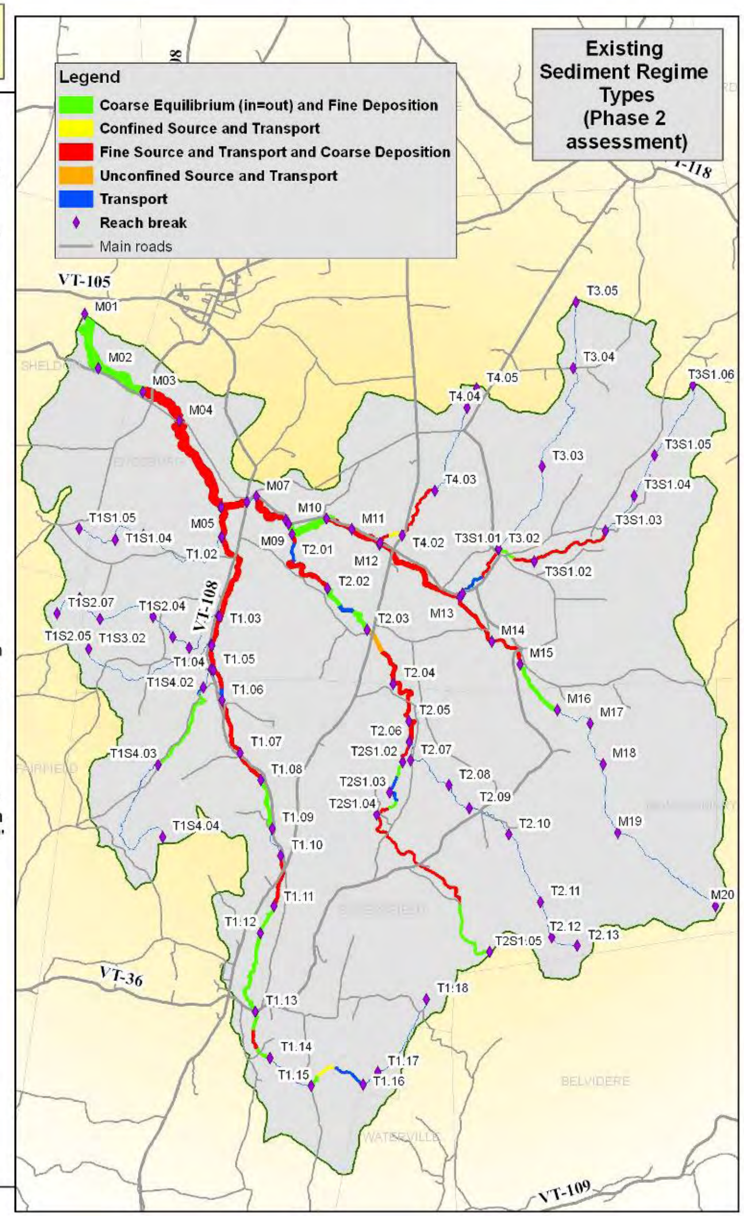


Figure 22. Sediment regime departure in the Tyler Branch watershed.

There are also numerous dispersed areas of ancient lake sediments and alluvial soils widely dispersed in the watershed (many of these are the hydric soils mentioned above). Due to the conversion of many CEFD sediment regimes to "Transport" sediment regimes, fine grained,"washload" materials are being transported long distances through the watershed, dropping out only when low velocity conditions are encountered. This contributes to downstream reaches aggrading fine materials that may not maintain the stability to contribute to redevelopment of more stable meanders and new floodplain development in historically incised reaches, instead concentrating deposition at channel constrictions and building on in-stream depositional features (e.g., enlarged but less stable point bars, mid-channel bars, steep riffles). This dynamic characterizes the "Fine Source & Transport and Coarse Deposition" (FSTCD) sediment regime current in much of the watershed, and given the series of floods that have occurred in the watershed in the last two decades likely represents the movement of flood-related sediment discharges through the stream network. Large woody debris appears to play an important role in slowing the transport of both water and sediment in upstream reaches, and beaver ponds and alder meadows in numerous of the old lake sediment areas appear to play a critical role in similarly attenuating both flow and sediment.

Channel evolution

Once a stream has entered a state of disequilibrium, it will begin a series of channel adjustments or evolutions to fulfill the physical mandates of restoring equilibrium. Schumm (1977 and 1984) has described five stages of channel evolution for reaches where the stream has a bed and banks that are sufficiently erodible to be shaped by the stream over time ("F-model" evolution; Fig. 23). The five stages of channel evolution for F-model evolution are paraphrased from the SGA protocols (VT-RMP geoassesspro 2007, Appendix C) as follows:

I. Stable — in regime, reference to good condition. Insignificant to minimal adjustment; planform is moderately to highly sinuous.

II. Incision — Fair to poor condition, major to extreme channel degradation. High flow events are contained in the channel, and channel slope is typically increased.

III. Widening/Migration — Fair to poor condition, major to extreme widening and aggradation. (An incised, entrenched and widened channel is an "F-type stream", hence F-model evolution)

IV. Stabilizing — Fair to good condition, major reducing to minor aggradation, widening and planform adjustments

V. Stable — In regime, reference to good condition. Insignificant to minimal adjustment.

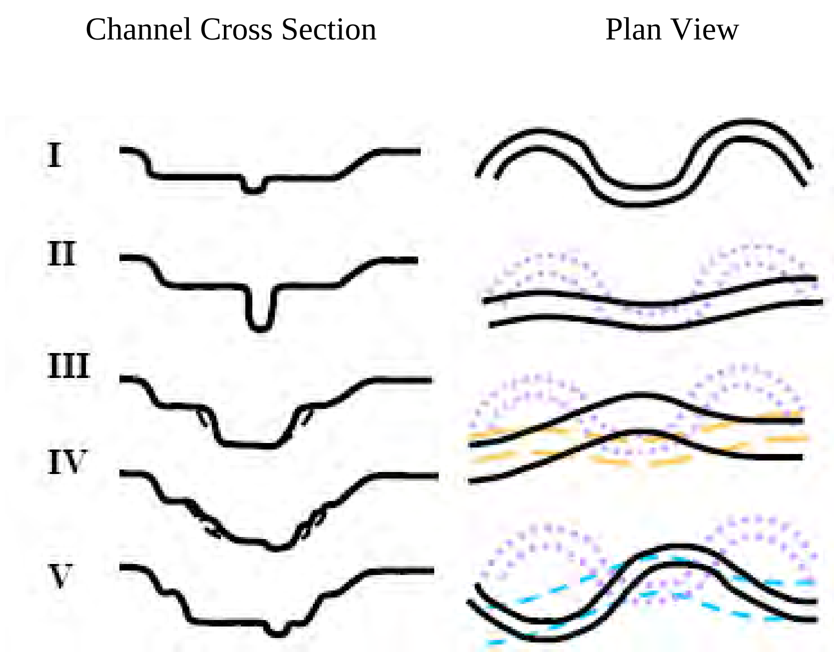


Figure 23. Channel evolution process showing channel downcutting or incision in Stage II (cross section), widening through Stages III and IV, and floodplain reestablishment in Stage V. Stages I and V represent equilibrium conditions. Plan view shows straightening and meander redevelopment that accompany cross-section changes, a primarily flood-driven process often taking place over decades (VT-RMP RCPG 2007).

Due to the coarse substrates and significant numbers of bedrock grade controls present in the Tyler Branch watershed, a number of assessed streams also exhibited a second model of channel evolution ("D-model" evolution) that is more typical in areas where a stream does not incise due to these constraints and instead evolves primarily through lateral movement. The three stages for D-model channel evolution are paraphrased from the SGA protocols (VT-RMP geoassesspro 2007, Appendix C) as follows:

> **I. Stable** — in regime, reference to good condition. Insignificant to minimal adjustment; planform is moderately to highly sinuous.

Then either of the following Stage II scenarios may occur:

> **Stage IIc. Widening/Migration** — Widening and migrating laterally through bank erosion caused by increased stream power. The balance between stream power and boundary materials is re-established when the slope flattens after a process of channel lengthening and increased sinuosity.

> **Stage IId. Braiding** — Extreme deposition and braiding, with water flowing in multiple channels at low flow stage ("D" stream type). Channel width narrows through aggradation and the development of bar features. Main channel may shift back and forth through different channels and chute cut-offs, continuing to erode banks or terraces.

> **Stage III. Stable** — Channel adjustment process is complete (back to a B, C or E stream type).

Phase 2 work assessed a majority of stream segments in the Tyler Branch watershed corridor planning area at Stage III or IV of F-model channel evolution, with widening and planform adjustments following historical incision (Fig. 23). A number of segments downstream of the dams on Bogue Branch (reachT2.05), Tyler Branch (reach M14), and Bakersfield village on The Branch (dams in reaches T1.04, T1.09, T1.11) were noted in stage II. Undammed tributaries in East Enosburgh (T3and T3S1) were also noted in stage II, possibly due to the impact of heightened flows..

Segments in bedrock controlled areas (T2.01, T2.02, T1S4.02A) and areas dominated by beaver activity (T1.13A and C, T1.15A,T1S4.02B) were indicated in reference, stage I channel evolution. Other bedrock-controlled areas in segments T1S4.02C on Beaver Meadow Brook in Bakersfield (stage IId) and T3.01A on Beaver Meadow Brook in Enosburgh (stage IIc) both were in D-model adjustment processes.

Segment T2S1.04D, located in the upland saddle between Peaked Mountain and the Cold Hollow Mountains, is a largely bedrock-controlled segment that was assessed in stage II of an F-model evolution, largely due to its role in current watershed dynamics. There are numerous pockets of deeper soils and accessible floodplain in the segment as well, where the channel is capable of incising further and losing access to this valuable floodplain. These exist in a patchwork, intermixed with numerous areas of shallow- to-bedrock soils. Shallow-to-bedrock areas were evidencing either stage IIc or stage IId of a D-model evolution, with single-thread or braided channels flowing over the bedrock and frequent channel avulsions eroding terrace sideslopes. These were particularly evident because of the recent flash flooding in the watershed. In the areas of deeper soil pockets, headcuts had begun to erode up or toward roads within the sugarbush access network, posing risk to these roads where small tributaries transversed a road. In places where the headcut was extending up a road, future flood events could send avulsed channels into these roads, and further headcutting might effectively turn these roads into extensions of the stream network. Even though this appears to be “just a small stream” in this area, this potential loss of floodplain attenuation places more water directly into the stream network at a more rapid rate in floods, exacerbating the heightened stream power that appears to be impacting many downstream reaches in this watershed.

Loss of access to historic floodplains, represented by departure from C-type streams to B- or F-type streams (entrenched in narrower valleys), was indicated in just three of twenty downstream reaches assessed in 2006 (in segments T1.01, T1.03 and T1.05A on The Branch) and two of twenty reaches assessed in 2008 (in segments M13C on Tyler Branch and T3.01B and C on Beaver Meadow Brook in East Enosburgh; Fig. 24). Although the wide dispersal of coarse bed substrates and ledge or bedrock grade controls in the Tyler Branch watershed has helped to limit channel incision and complete loss of floodplain, partial restriction of floodplain was indicated in Phase 2 assessments on numerous reaches (Fig. 13). This reduction in floodplain capacity appears to be combining with the significant changes in hydrology in the watershed to increase stream power and sediment transport, particularly noticeable in heightened flood impacts, while also reducing the amount of fine sediment storage on floodplains.

Heightened hydrologic inputs in “urban” areas, combining increases in impervious surfaces in conjunction with increased numbers of stormwater inputs, can also push downstream reaches into adjustments. These dynamics may be contributing (in

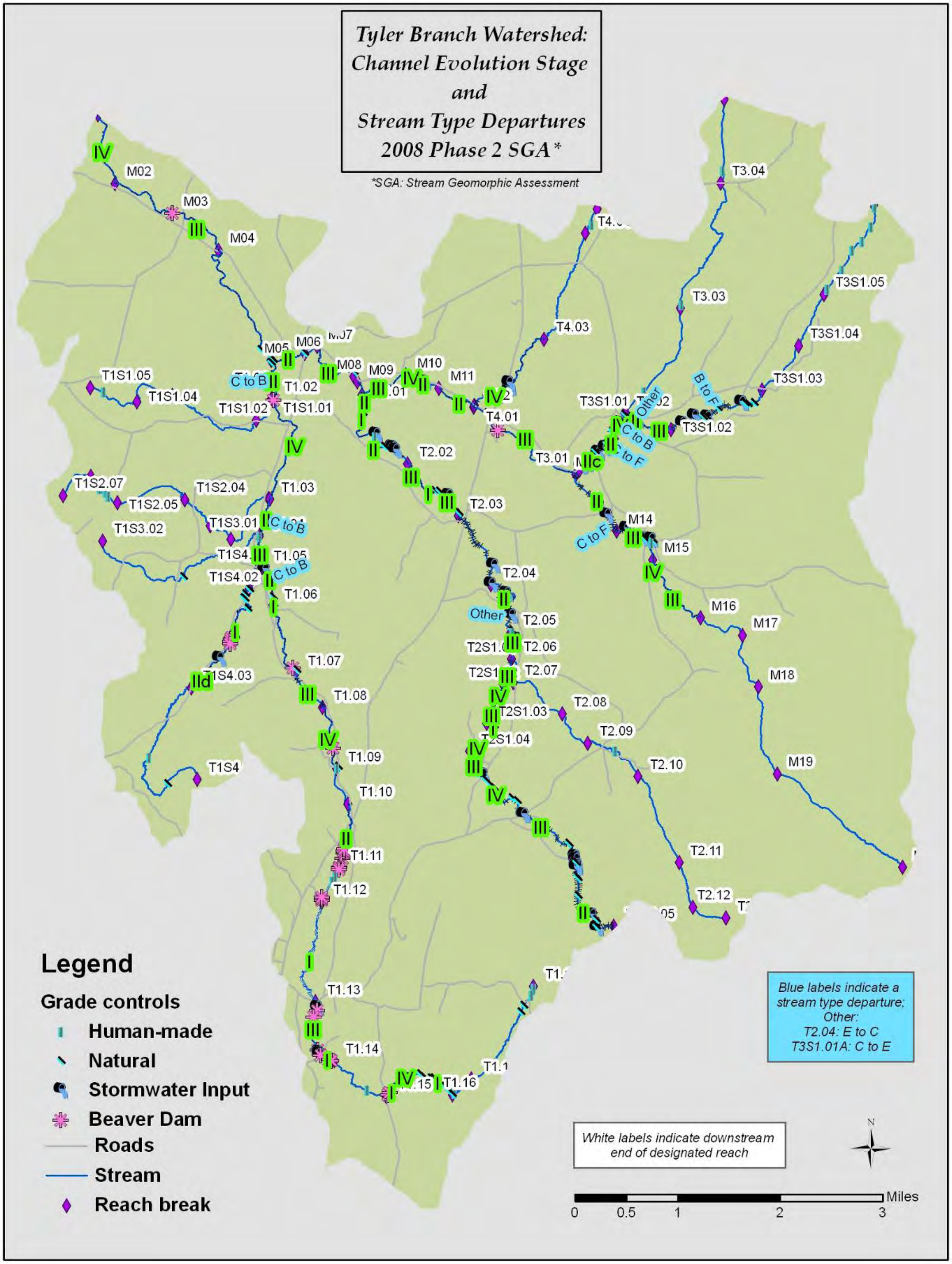


Figure 24. Channel evolution stage and stream type departures map for Phase 2 assessed reaches in the Tyler Branch watershed corridor planning area.

conjunction with “sediment starving” and localized heightened hydrologic impacts below dams) to observed adjustments, including stream type departures, occurring along The Branch downstream of Bakersfield village (Fig. 24). Historic bed degradation may have been further enhanced by historic stream diversion into Beaver Meadow Brook and its tributary in East Enosburgh (see discussion in Sec. 3.1.1, Watershed-scale hydrologic changes). Channel adjustments due to increased flows can be difficult to remediate in downstream reaches (Booth and Jackson 1997), potentially prolonging the stages of disequilibrium in these streams and leaving them open to heightened flood impacts in future events. This places a premium on attenuation of high flows in upstream reaches in particular, and increases the importance of:

a) protecting and maintaining floodplain access even on small streams high in the watershed;

b) limiting development and encroachments within stream corridors and narrow valleys in these areas;

c) establishing and maintaining woody buffers in riparian corridors and

d) managing stormwater inputs to minimize direct discharges to streams.

“Other” stream type departures (Fig. 24) in reaches T2.04 and T3S1.01 were primarily due to planform changes related to hydrologic impacts as well. In reach T2.04, extensive straightening and a recent channel avulsion have dramatically reduced the sinuosity of an E-type stream, as well as increasing the width to depth ratio (to the cusp of C/E type delineations based on this parameter). Current sediment deposition in point bars appears to be part of this stream channel’s evolution back toward a narrower channel and more sinuous planform. In contrast, Segment T3S1.01A in East Enosburgh is a C-type reference stream that currently has a much lower E-type width to depth ratio (although sinuosity is also low and not characteristic of an E stream) due to sediment windrowing and berming in the vicinity of an undersized bridge following flood impacts in 1997 or 1998. The coarse materials used in the windrow and berm are likely to curtail the rate of channel evolution and exacerbate the impacts of increased stream power.

Constraints to channel evolution

Bedrock and ledge outcrops interspersed throughout the corridor planning area in the Tyler Branch watershed represent significant constraints to vertical channel evolution, and are a “given” in this respect (and have likely limited loss of valuable floodplain access through channel downcutting). The effects of these are considerably increased (as constraints to evolution) by the sediment starving and localized increases in stream power downstream of dams on The Branch, Bogue Branch and Tyler Branch. While possible removal of these dams might help considerably in terms of channel evolution and restoration of equilibrium conditions, any of these undertakings would likely be costly and have numerous other considerations (aesthetic, historic, and social attachments rank high on the list). As discussed in much of this report, these constraints (and the substrates present in bank materials) predispose many of the streams in the watershed to lateral migration as a primary means of channel evolution. This dynamic places a premium on minimizing lateral constraints to channel evolution along the streams of the Tyler Branch watershed. Human-built lateral constraints are currently concentrated along the Tyler

Branch Rd. between West Enosburgh and Gilbert's Tannery (Tyler Branch reaches M07 – M11), around East Enosburgh (upstream half of reach Tyler Branch reach M12 up to the M13 reach break and continuing up Beaver Meadow Brook reach T3.01), along Rte. 108 downstream of Bakersfield village to the Enosburgh town line (The Branch reaches T1.04 – T1.08), along Beaver Meadow Brook in Bakersfield (reach T1S2.04), and along the East Sheldon Rd. (Tyler Branch reach M.02)(Fig. 25).

Attenuation assets

Given the significant number and degree of lateral constraints along the Tyler Branch Rd., protection of attenuation assets at upstream tributary confluences in the eastern portion of the watershed will play an important role in mitigating flood impacts on downstream reaches and reducing the distance that fine washload sediments are transported through (and out of) the watershed (Fig. 25). Key assets include:

- Beaver Meadow Brook tributary segments T3S1.01B and T3S1.02A in East Enosburgh
- Tyler Branch segment M13A and reach M15
- Tyler Branch tributary segment T4.01A at the Pattee farm in Gilbert's Tannery and Beaver Meadow Brook tributary segments T3S1.02B and C play important but lesser roles

Although the houses, roads and driveways used to map lateral constraints do not appear to impact Bogue Branch significantly, intensive agricultural use has contributed to extensive straightening noted along this stream (Fig. 16) and increases the value of upstream reaches for attenuating flow in particular. It also increases the importance of segment T2.01A, at the confluence of Bogue Branch and Tyler Branch, as an attenuation asset for both flow and sediment. Although there is no built infrastructure in this segment, current land use (cultivated fields, pasture and significant cut and split firewood storage) does appear to maintain the stream against the left valley wall in this segment, potentially masking what may in fact be an alluvial fan.

Key attenuation assets in upstream reaches of Bogue Branch and its tributaries include:

- Segments T2S1.04D in the Branon sugarbush and T2S1.04C downstream of it. T2S1.04D currently still functions with a Coarse Equilibrium and Fine Deposition (CEFD) sediment regime but is currently experiencing adjustments that could lead to significant loss of valuable floodplain (see discussion in this section above, in relation to channel evolution). T2S1.04C appears to be a natural alluvial fan that has been converted to a Fine Source and Transport and Coarse Deposition (FSTCD) sediment regime.
- Segments T2S1.03C and T2S1.04A at the confluence of Bogue Branch and Ross Brook. These appear to be a high deposition zone that has currently been converted to a FSTCD sediment regime as well, with moderate-intensity agriculture (pasture/hay/large garden) presenting low-level lateral constraints and a functional CEFD segment (T2S1.03B) just downstream.

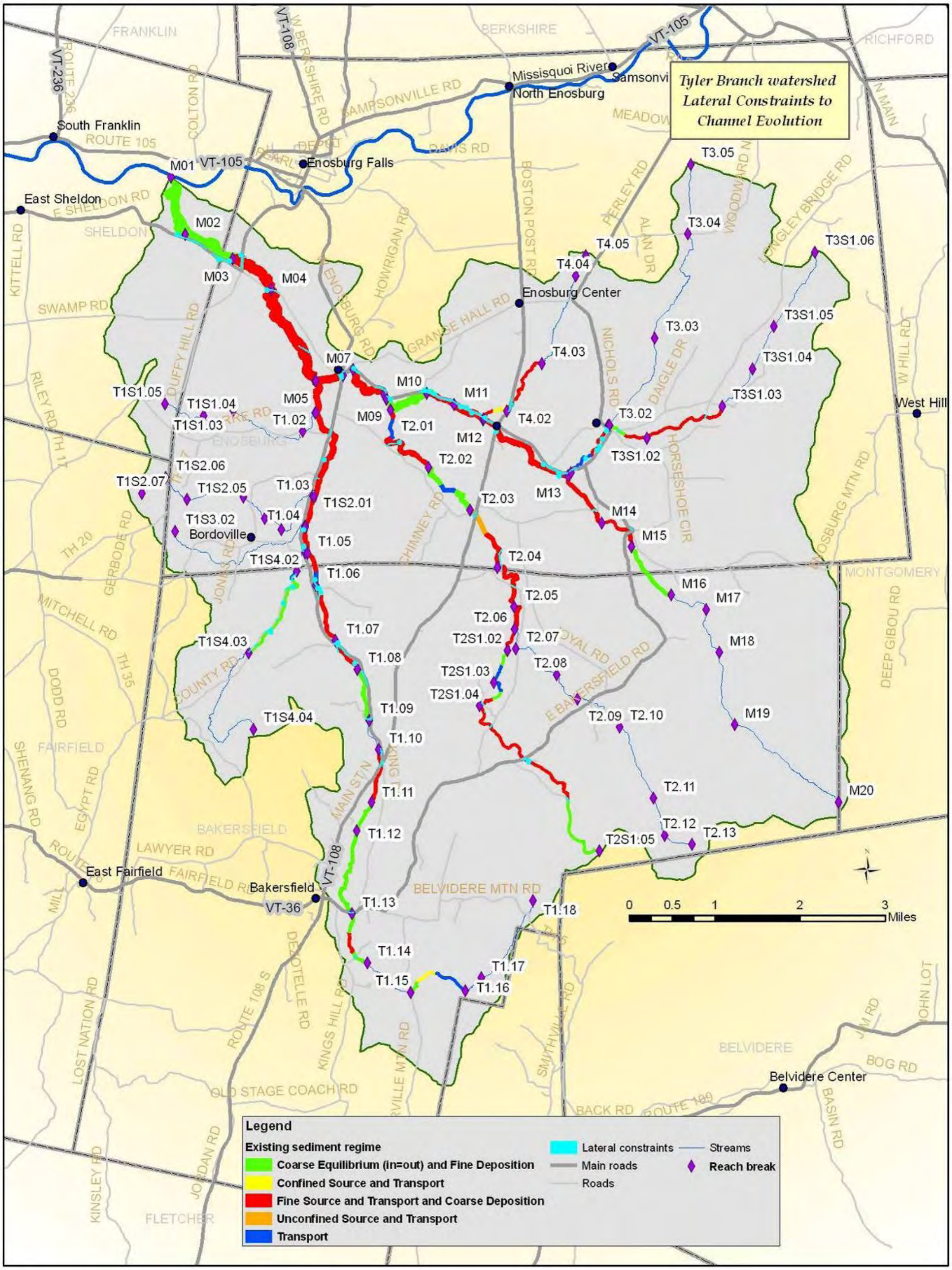


Figure 25. Map of existing sediment regime in conjunction with vertical and lateral constraints to channel evolution in the Tyler Branch watershed corridor planning Project area.

Although lateral constraints are more prevalent along The Branch than along Bogue Branch, beaver-impacted areas that play key roles as attenuation assets in the upstream areas The Branch appeared to be in fairly good shape during 2006 and 2008 assessments. Key attenuation assets in this portion of the watershed include:

- At least some portion of all reaches from T1.08 upstream to the downstream portion of reach T.1.15; and
- T1S4.02 on Beaver Meadow Brook in Bakersfield

Assessment of all of these indicated current functionality as CEFD sediment regimes (Fig. 25). The fine substrates in this portion of the watershed make these streams very sensitive to changes however, and fully functional floodplains play a critical role in retaining fine sediments and attenuating flow on these types of streams. The Town of Bakersfield took a major step in protecting these assets through adoption of 100 ft setbacks along streams at their March 2009 Town meeting (http://nrpcvt.com/Zoning%20Bylaws/Bakersfield%20Zoning%20Bylaws.pdf, p.17). Maintenance of well-vegetated buffers along these streams further aids the functional capacity of these floodplains in attenuating flow and fine sediment loads. Channel straightening, even for the short distances often associated with stream crossings, can reduce the highly sinuous nature observed on such streams under reference conditions, reducing floodplain access, increasing stream power, and initiating adjustments upstream and downstream in these highly sensitive materials.

Incisional processes and conversion to FSTCD sediment regimes noted in the western portion of the watershed (Figs. 12 and 13) appear to be concentrated downstream of dams located along The Branch, likely related to the combination of fine-grained, highly sensitive substrates and the effects of stream power heightened by straightening, flow regulation and the elevation drop below these dams as well as land use changes (increased development; see Sec. 5.1.1, Watershed – scale hydrologic alterations). These impacts and adjustments will be difficult to address without major investments and significant changes associated with dam removal, thus increasing the importance of protecting the current upstream attenuation assets in beaver-impacted areas as well as minimizing further corridor encroachments downstream that would contribute to heightened stream power impacts through any further straightening or imposition of lateral constraints.

Existing sediment regime summary

To summarize, the existing sediment regime in the eastern portions of the Tyler Branch corridor planning area (Bogue Branch and Tyler Branch and their tributaries) features:

- Increased stream power heightened by the effects of “sediment starving”, particularly of coarse sediments, at prominent dams on Bogue Branch and Tyler Branch.
- Stream power impacts are elevated in eastern portions of the watershed, in part due to stream diversion, flow regulation and straightening, but also due to high annual precipitation levels related to effects of the Cold Hollow and northern Green Mountains, and passed to downstream reaches.

- Particularly in upstream portions of the eastern portions of the watershed, coarse sediments line active channels and are being further recruited from tributaries, mass failures and gullies in unconsolidated geologic materials along valley walls, as well as new channels cut by avulsions.
- These coarse sediments tend to remain in place in all but the highest flows, contributing to bed and bank materials that are resistant to erosion and predispose streams to lateral migration and channel avulsions as a primary means of balancing stream power, slope gradients, and sediment loads.
- Coarse sediments are contributing some to enlarged bars in the process of channel evolution, but due to a series of floods in the 1990s in particular appear to be moving through the stream network in "sediment slugs", accruing at channel constrictions (both natural and human-constructed) and features such as braids and mid-channel bars when sediment loads exceed the transport capacity of the stream.
- Fine sediments from eroding unconsolidated materials are contributing to elevated washloads being transported long distances downstream until they encounter low velocity conditions.

The combination of increased stream power and sediment discontinuities in the eastern portion of the watershed raises the following key issues on Bogue Branch, the upstream portions of Tyler Branch (particularly above reach M12 in Gilbert's Tannery), and their tributaries assessed in 2008:

1. Heightened stream power is difficult to remediate downstream, increasing the importance of opportunities for attenuating flow in upstream reaches in particular
2. Good opportunities for attenuating flow exist at naturally occurring alluvial fans and similar high deposition zones, but increase the importance of accommodating lateral movement of the stream (which often appears to occur across the entire valley floor over time)
3. Coarse bed and bank materials predispose the streams in this portion of the watershed to channel avulsions and rapid lateral migration as a primary means of channel evolution, placing a premium on minimizing corridor encroachments both to accommodate stream processes and for flood hazard avoidance and mitigation
4. Due to the resistance to erosion of these bed and bank materials, sediment windrowing can significantly retard the process of channel evolution and further increases the impacts of elevated stream power on downstream reaches
5. Well vegetated woody buffers play a large role in mitigating the impacts of elevated stream power by decreasing the rate at which water enters the stream, physically diffusing stream power in floods, and contributing to meander development and formation of depositional features (sediment retention) through contributions of large woody debris (particularly important in headwaters streams)
6. Stormwater inputs increase streampower and the potential for downcutting, and should be managed to avoid direct inputs to the stream as much as possible

In western portions of the watershed, along The Branch and its tributaries, elevated precipitation appears to be less of a driver of stream dynamics (although the most upstream reaches of The Branch are affected similarly to the eastern portions of the watershed). Stream power does appear to be elevated downstream of dams on The Branch, however, and with streams in the western portion of the watershed highly to extremely sensitive to changes in watershed inputs (largely because of fine-grained geologic materials present along the streams in this portion of the watershed) stream downcutting does appear to be occurring in downstream reaches. These factors raise the following issues on The Branch and its associated tributaries assessed in 2008:

1. Downstream impacts and adjustments on The Branch will be difficult to address without major investments and significant changes associated with dam removal, increasing the importance of upstream attenuation of flow in particular; upstream sediment load attenuation is also important because fine grained washload materials are being transported at an elevated rate and level by the increased stream power in downstream reaches
2. Low-gradient, beaver-impacted areas play an important role in attenuating flow and sediment loads and are highly to extremely sensitive to imposition of lateral constraints including development encroachments and structural measures designed to maintain the stream in a straightened or fixed location
3. Maintenance of undisturbed native vegetation in buffers along low-gradient streams in these areas helps reduce erosion and store fine sediments on floodplains more effectively
4. Well vegetated woody buffers in the headwaters of The Branch help decrease the rate at which elevated levels of precipitation in this area enter the stream, stabilize erodible materials on valley sideslopes, and play a large role in meander development and formation of depositional features (sediment retention) through contributions of large woody debris

5.2 SENSITIVITY ANALYSIS

The preceding departure analysis identifies the watershed and reach-scale stressors that help explain the sediment regime departure currently existing in the Tyler Branch corridor planning area. Designing stream corridor protection and restoration projects that are compatible with channel evolution processes, and prioritizing them at the watershed scale, also require an understanding of stream sensitivity.

Sensitivity refers to the likelihood that a stream will respond to a watershed or local disturbance or stressor, and an indication as to the potential rate of channel evolution (VT-RMP geoassesspro 2007, Phase 2, Step 7.7; VT ANR RCPG 2007, Section 5.2). While every stream changes in time, a sensitivity rating indicates that some streams, due to their setting and location within the watershed, are more likely to be in an episodic, rapid, and/or measurable state of change or adjustment.

The large majority of assessed reaches in the Tyler Branch watershed corridor planning area are Highly to Very Highly sensitive to disturbance and stressors, and thus also capable of a relatively rapid response (channel evolution to reestablish equilibrium conditions) if stressors are addressed (Fig. 26). This is in part due to the selection of mostly C-type streams for assessment, which are by nature relatively sensitive and capable of recovery to equilibrium conditions in response to restoration efforts (Rosgen 1994). Most reaches along The Branch are Highly sensitive (but in Good or Reference geomorphic condition), with a small number of beaver-impacted and bedrock-controlled portions (in Reference or Good condition) rating Moderate sensitivity (Fig. 26). Reaches in the eastern portion of the watershed tend to be even more sensitive, with ratings predominantly in the Very High category and geomorphic condition predominantly in the Fair range; two segments exhibiting stream type departures due to loss of access to floodplain (T3S1.02B and M13C) are Extremely sensitive (and Poor to Fair condition).

In general, the high sensitivity of a majority of reaches throughout the watershed indicates good possibilities for success of passive geomorphic projects, which would allow the river to utilize its own energy and watershed inputs to reestablish meanders, fuller access to floodplains, and self maintaining equilibrium conditions over time. The high flow inputs and high energy dynamics in eastern portions of the watershed in particular also place active restoration projects at high risk of failure, with engineered approaches susceptible to flash flooding and rapid planform changes. Providing ample room for these processes to occur will be a critical aspect of restoration efforts. High flow inputs and erosion resistant bed and bank materials in the eastern portions of the watershed also mean that bank armoring and sediment windrowing will significantly restrict and delay evolution processes and reestablishment of equilibrium conditions.

Only segment T2.01B, a bedrock-controlled area in Reference condition at the base of Bogue Branch, was classed with Very Low sensitivity (Fig. 26). A closer look at the distribution of moderately sensitive reaches in this portion of the watershed (Fig. 27) indicates that half of reach T2.02 upstream of this area is moderately sensitive. The lower level of sensitivity in portions of these reaches, in conjunction with limited spatial extent and current land use constraints on functionality as an attenuation asset in reach T2.01 at the confluence of Bogue Branch and Tyler Branch (see discussion in Sec. 5.1.4 above in regards to attenuation assets and lateral constraints) indicates that channel evolution in this area may be slow. Moderately sensitive reaches are also located on both up and downstream ends of the high deposition zone at the confluence of Ross Brook and Bogue Branch (Fig. 27). Prioritization of restoration efforts on upstream reaches is recommended as the most effective restoration strategy on Bogue Branch, from a watershed view, due to expectations of a slower rate of channel evolution in these areas.

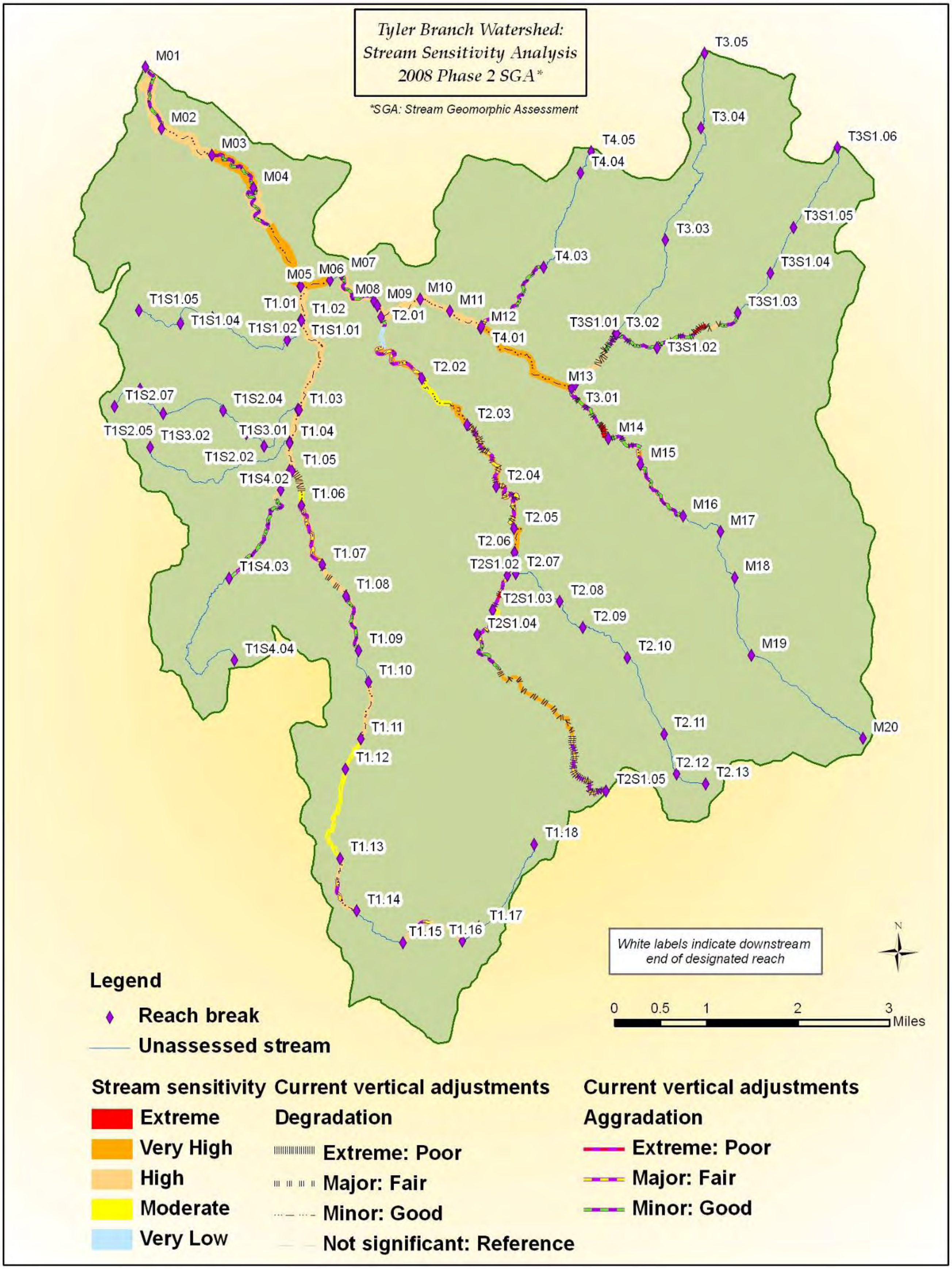


Figure 26. Sensitivity analysis: Stream sensitivity and current adjustment map for the Tyler Branch watershed corridor planning area.

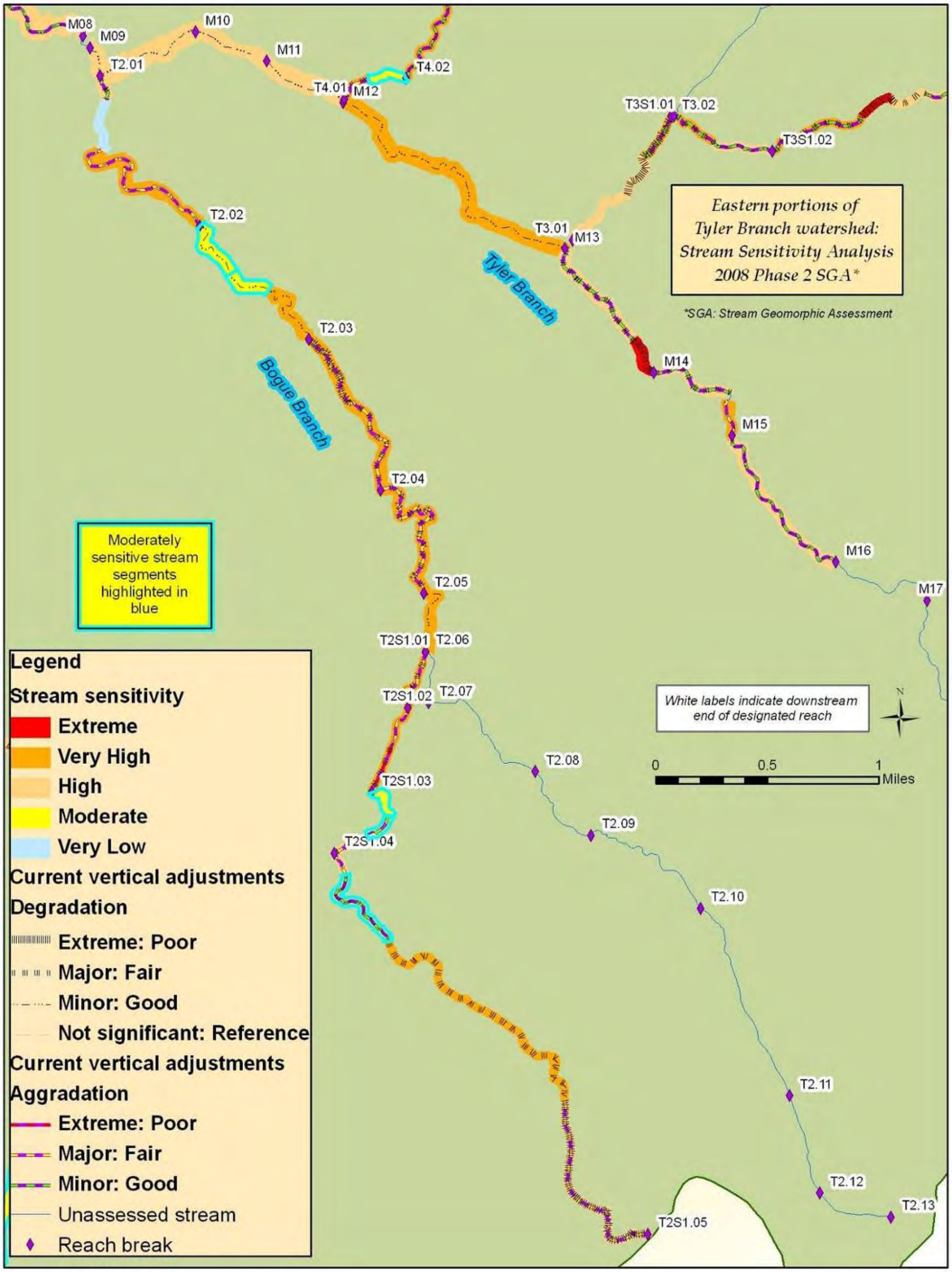


Figure 27. Distribution of moderately sensitive reaches in eastern portions of the Tyler Branch watershed indicates that channel evolution may be slower in key areas along Bogue Branch, suggesting that watershed strategies might achieve better results by focusing on restoration of upstream reaches first. Moderate sensitivity in segment Tyler Branch tributary segment T4.01B increases the importance of T4.01A as an attenuation asset.

6.0 PROJECT IDENTIFICATION

6.1 REACH DESCRIPTIONS—PRELIMINARY PROJECT IDENTIFICATION

With these overarching considerations, preliminary project identification for reaches included in the Tyler Branch watershed 2008 Phase 2 assessment is presented on a reach-by-reach basis in the following pages. “Left bank” and “right bank” in the reach descriptions are referenced looking downstream. Reach maps include a “belt width corridor” drawn on either side of the stream. The width of this corridor (generally a minimum of 3-4 times the stream channel width) is based on over 30 years of research and data collected from hundreds of streams around the world, and approximates the extent of lateral adjustments likely to occur over time in a meandering stream type (VT ANR 2007 Protocols, Appendix H). “Human investments within the belt width inevitably result in structural constraints placed on the channel adjustment process to protect those investments and address associated threats to public safety. These threats will be largely avoided by recognizing the hazards created by development, incompatible with channel adjustments, within the critical belt width” (VT ANR 2007 Phase 2 Protocols, p.17). Background imagery for the reach maps is from the National Agricultural Imagery Program (NAIP), dated 2003.

6.1.1 Preliminary project identification: Reach M13 – Tyler Branch mainstem, from the confluence of the mainstem and Beaver Meadow Brook (Enosburgh) to approximately 1000 ft upstream of the Sand Hill Road bridge.

Tyler Branch mainstem reach M13 is 3,975 ft long (0.75 miles) and was segmented during the Phase 2 process into 3 segments of 902 feet, 2,082 feet, and 992 feet in length. The reach is characterized by a Very Broad valley confinement type. Soil maps show the entire length classified as hydric soils, with a couple of areas mapped as forested wetland in the Vermont Significant Wetlands Inventory, indicating that this reach has the potential for being an important hydrologic attenuation asset. The Phase 1 process classified the reach as a C stream with a ‘b’ (2-4%) subslope, riffle pool bedform, and cobble substrate. Phase 2 assessment indicated these characteristics throughout M13A, but M13B has been bulldozed and has a planebed bedform. M13C has incised to the point that it is entrenched and was re-classified as an F stream with a riffle pool bedform.

Segment M13A retains a fairly undisturbed setting but appears to be quite dynamic. Channel planform adjustment indicators are common. Key features include:

- There is no armoring on this segment.
- There are 2 mass failures at the lower end of the segment.
- Dominant buffer on both banks is >100 ft.
- Cobble substrate appears to somewhat inhibit incision.
- Old channel beds in the valley indicate past channel movements through avulsion.
- The stream is in stage III, showing some historical incision but with widening, aggradation, and planform change dominating the active processes.
- Substrate is cobble and sensitivity rating is High, and geomorphic rating is Fair

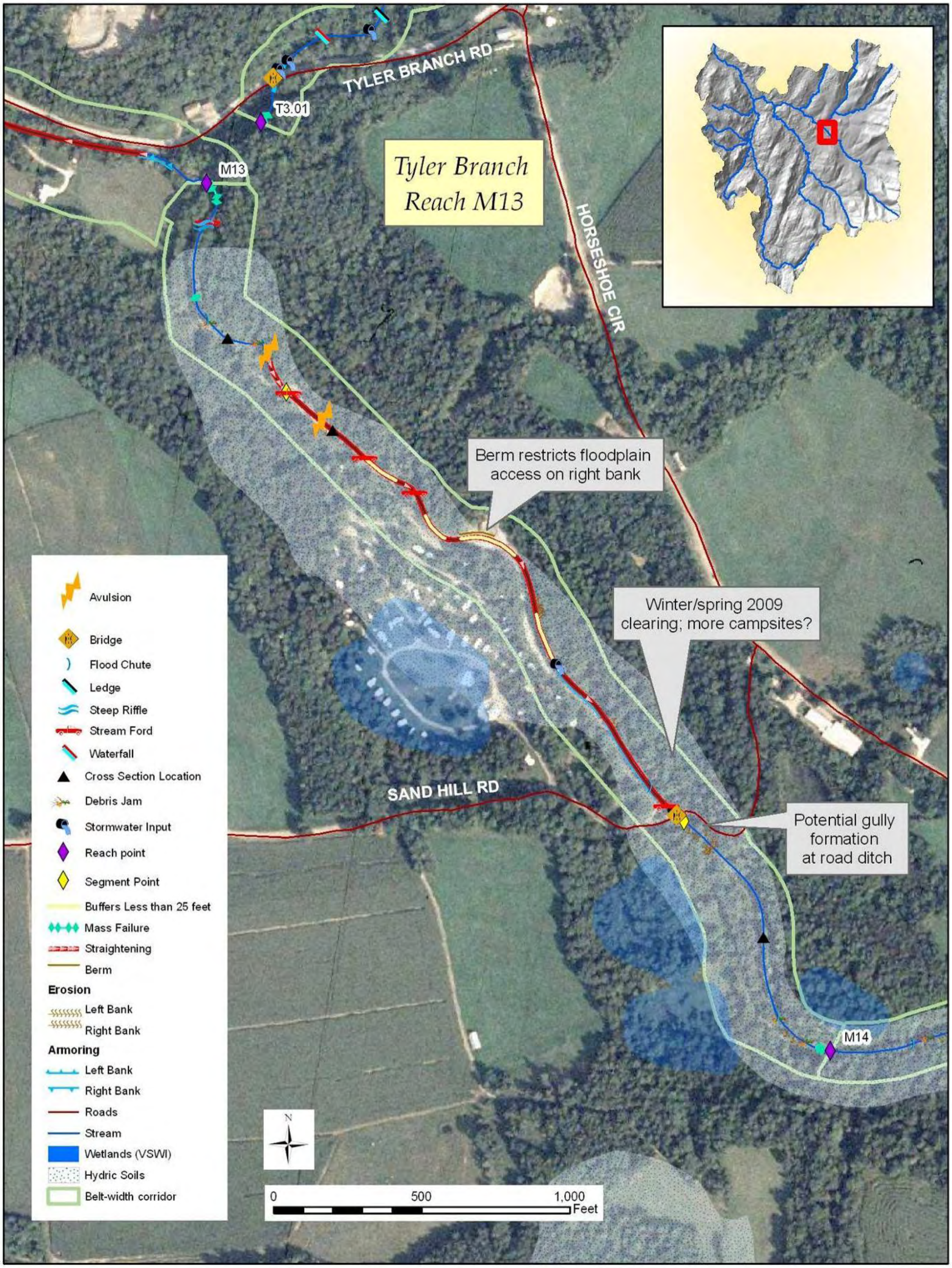


Figure 28: Tyler Branch Reach M13

Segment M13B (2,082 ft) is characterized by significant and ongoing mechanical manipulation. The campground owner has a bulldozer and appears to regularly cross the stream at multiple fords throughout the segment to carry out activities on the other side. After the 1997-98 flooding in this area, he channelized the stream and cleared out debris and sediment, particularly on the downstream end of the campground (pers.comm., Doug Snider, August 2008). Key features include:

- The entire segment has been straightened.
- There is >20% armoring along the left bank of this segment.
- Dominant buffer on the left bank and sub-dominant buffer on the right bank is 0-25 ft.
- There are two stormwater inputs to this segment (road ditch and drainage pipe).
- There is a bridge in the segment that has signs of deposition upstream.
- The stream is in stage II, with incision being the most active process. Recent manipulations make stream processes hard to read, but all processes are somewhat active.
- Substrate is cobble, sensitivity rating is High, and geomorphic rating is Fair.

Figure 29: Reach M13, segment B shows flooding disturbance (left) and left bank development and stream manipulation (right).

Segment C (992 ft) is characterized by incision and widening that are most likely occurring in response to manipulations in the segment downstream. Incision has occurred to the extent that there has been a C to F stream type departure. Upstream erosion and mass failures are contributing sediments to this segment. Key features include:

- There is no armoring, development, encroachment, or straightening in this segment.
- Dominant buffer on the left bank and sub-dominant buffer on the right bank is greater than 100 ft.
- The stream is in stage III, with historic incision and current widening and aggradation being the most active processes.
- Substrate is cobble, sensitivity rating is Extreme, and geomorphic rating is Fair.

Table 9. Tyler Branch Reach M13 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M13A M13B M13C	Protect river corridor	High High High	High High High	Y	Valuable attenuation asset upstream of confluence with Beaver Meadow Brook and downstream of highly erodible geologic formations; current significant stream manipulations; explore channel management easements at Brookside Campground
M13B	Plant stream buffer	Low	Low	Y	Development along left bank leaves bank exposed to erosion; low cost: current instability
M13B	Remove "berm" (actually an augmented windrow)	High	Moderate	N	Stream sediment windrow has removed coarse sediments from stream and restricts floodplain access off right bank but likely accessed in floods; may be protecting logging road
M13C	Replace Existing Bridge Structures	Low	Low	Y	When bridge is due to be replaced consider structure that allows for more lateral movement of the stream.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M13A M13B M13C	Restore incised reach	High	High	N	Address stormwater inputs and potential gully formation upstream of Sand Hill Rd.bridge; pursue high priority corridor protection downstream to ensure coarse sediment transport and unrestricted meander development (ties to step 1, corridor protection)

6.1.2 Preliminary project identification: Reach M14 – Tyler Branch mainstem, from upstream of the Sand Hill Road bridge to upstream of the East Bakersfield Rd. bridge near Horseshoe Circle-Enosburgh Mtn. Rd. junction

Reach M14 comprises roughly 3645 feet of the Tyler Branch mainstem extending from approximately 1000 feet upstream of the Sand Hill Rd. bridge to an open pasture upstream of the East Bakersfield Rd. bridge, near the junction of that road with the Enosburgh Mtn. Rd. and Horseshoe Circle (Fig. 30).

Reach M14 was assessed as 3 segments of roughly 2136 feet, 177 feet, and 936 feet in length. The short section in segment M14B comprises a 50 foot waterfall and a 10 foot dam located in a bedrock gorge. With much of the elevational gradient of the overall reach accounted in the waterfall and dam of segment M14B, both M14A and M14C were classified as C type streams, although both segments were just above the lower limit of a 'b' subslope (2-4% slope).

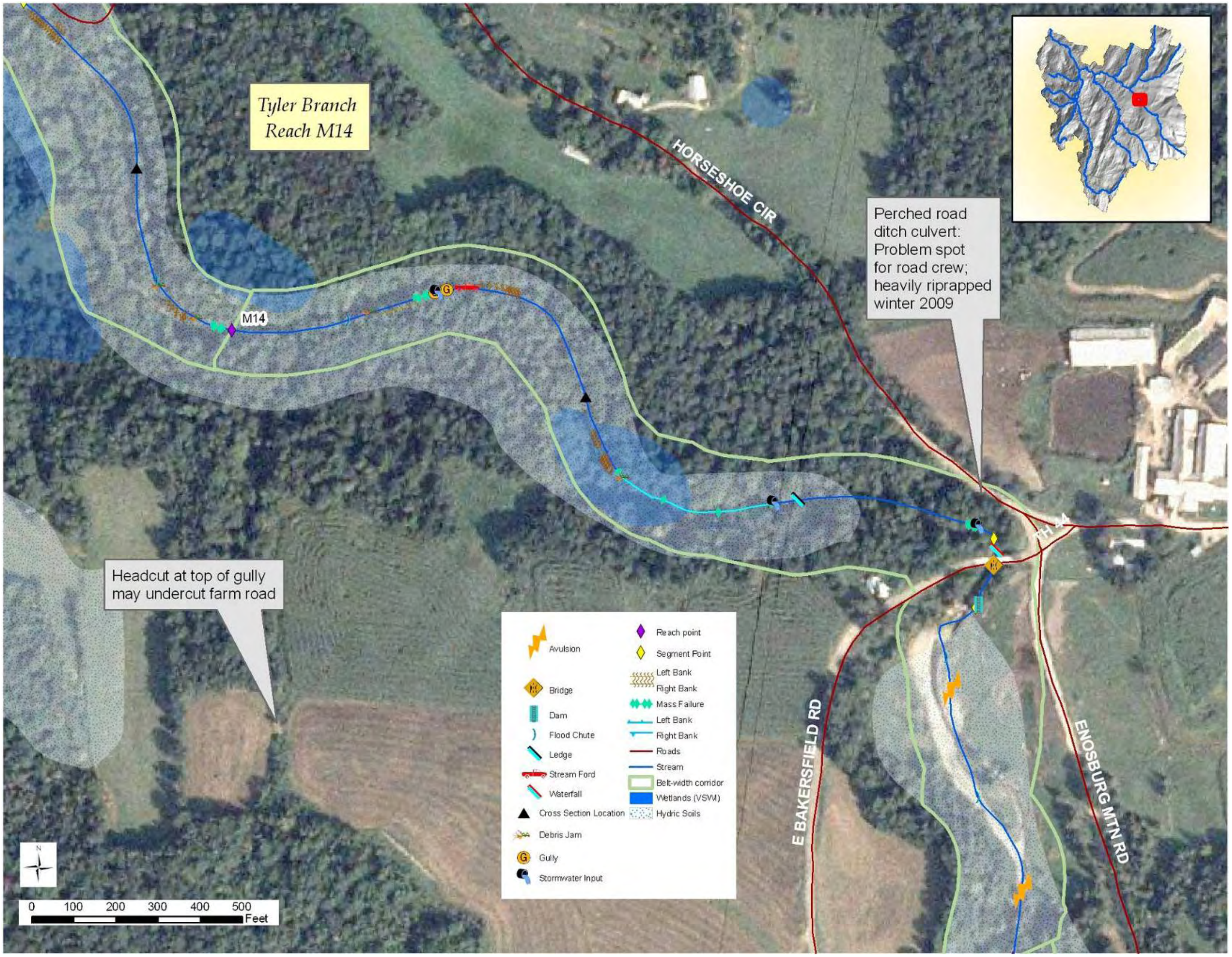


Figure 30. Tyler Branch mainstem reach M14 map

Segment M14A, covering nearly two thirds of the reach, is a C-type stream with a ‘b’ subslope (2-4%), cobble substrate and a reference planebed bedform (neither riffles nor steps setting up regularly), situated in a largely forested, steep-walled valley. Distinguishing characteristics of the segment included:

- Average valley confinement on the lower end of a Broad classification, with narrower portions of the valley limiting floodplain to a more characteristic B-type stream entrenchment.
- Minimal corridor encroachments, except:
- Thirty feet or so of Horseshoe Circle on the right bank at the head of the segment has been a challenging spot for local road crews and was originally identified as a likely project area: road ditches outlet at a perched culvert above the extremely steep right valley wall, triggering repeated bank failures in high flows that continue to cut the bank back underneath the culvert (Fig. 31). This area was heavily riprapped after the assessment, in late winter or early spring 2009. A small patch of Japanese knotweed at this site was likely imported with fill used for previous attempts at addressing the bank failures, and was one of the only places that invasive plants were observed in the watershed during 2008 assessments. Rapid response would be extremely helpful in preventing further spread of this plant, which has spread rapidly along watercourses in other parts of the state and is difficult to manage once it becomes established.

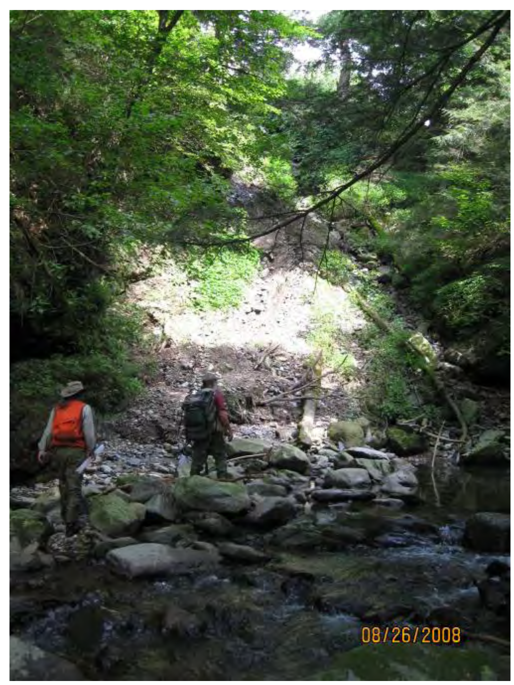


Figure 31. Bank failures triggered by stormwater inputs that carry runoff from road ditches to a perched culvert above a steep valley wall in segment M14A have repeatedly cut back the road edge (left) and triggered mass failures on the valley wall below (right). The area was heavily riprapped in early 2009. Japanese knotweed in the picture at left was one of the few incidences of invasive plants evident in reaches assessed in 2008, and might be limited from further spread by a rapid response.

- Mass failures averaging 60-70 ft tall along 450 feet of the left bank and 35 feet of the right bank, with older mass failures along the valley walls significantly healed over and revegetated
- A gully (roughly 200 feet long, 20 feet deep and 30 feet wide) that appeared to have opened very recently on the left valley wall in intense storms (Fig. 32). The

gully opened beneath a small red maple/hemlock forested wetland, cutting through highly erodible unsorted (ice-contact) substrates, even though the extremely steep valley wall was well forested with mature trees. A headcut at the top of the hill has the potential to undercut a farm road that crosses from corn and hayfields accessed off the East Bakersfield Rd. toward a smaller hayfield to the west (Wright farm; Fig. 30)

- Three stormwater inputs: two field ditches (one at the head of the gully) in addition to the road ditch noted above
- A 30 foot wide bedrock constriction near the head of the segment, just downstream of the bedrock gorge
- The reach is historically incised, likely related to a combination of flows intensified through the bedrock gorge in the next segment upstream as well as flow regulation and "sediment starving" at the old mill dam
- Coarse substrate makes the stream bed and banks resistant to erosion (though still erodible in high flows), with a consequent increase of stream power on the valley walls
- The stream is in stage III evolution, primarily widening; geomorphic condition is Fair and stream sensitivity is High

Figure 32. A classic gully opened on the left valley wall of segment M14A (left) in summer 2008 storms, resulting in a significant sediment discharge to the stream that will contribute sediments to stream dynamics for some time to come (right).

Segment M14B, because it is in a bedrock gorge, was excluded from Rapid Geomorphic and Rapid Habitat Assessments per Phase 2 protocols. Assessed features included:

- A-type stream with cascade bedform, 50 foot waterfall and 10 ft dam
- Mixed forest buffers, >100 ft (26-50 ft subdominant) on the left bank and 51-100 ft (6-50 ft subdominant) on the right bank
- Straightened by virtue of flow regulation through the old mill dam area
- The mill dam appears to play a significant role in limiting coarse sediment transport to downstream reaches; resulting "sediment starving" has likely contributed to channel incision in downstream reaches. Removal of this dam would benefit

sediment continuity, but would not benefit fish passage due to the waterfalls just downstream, which likely prevent passage regardless. Possible conflicts with development at Brookside campground downstream might result from changes in reach dynamics if these sediments were released by dam removal; headcutting upstream would also need to be assessed, although the upstream area is currently pastured, has no encroachment conflicts, and is in an alluvial fan area that might well "wash out" nickpoints with new sediments.

An open pasture at the Wright Farm comprises the 962 feet of segment M14C, and occupies the site of an old mill pond upstream of the dam. Mr. Wright (senior) said that a grist mill, saw mill, and shingle mill all operated at this site at one time. Dean Wright, who appears to be the primary farm operator at this time, stated that although they have occasionally considered fencing the cows out of the stream in this pasture it was easier to "let nature do the watering". Due to the coarse cobble substrates present and the low bank slopes along the stream there was remarkably little erosion or impacts from the cow access evident.

Other key features of segment M14C included:

- C stream with a cobble substrate and a slope that is right on the cusp of the 2.0% that marks transition to a 'b' subslope
- Widened channel (width/depth ratio 26.9)
- Buffers 0-25 ft on both banks throughout most of the segment
- Multiple flood chutes and channel avulsions that have aggraded significantly; the channel avulsions are currently also functioning as flood chutes
- Historical straightening is evident in the angle of approach to the dam, but the stream is now undergoing significant planform change
- It appears possible that the confluence with Cold Hollow Brook may have been historically altered by upstream diversion, to the east of Enosburgh Mtn. Road, into this segment (see further discussion in the description of Reach M15)
- The stream is historically incised and now in stage IV, with lateral migration common and ephemeral through cobble and gravel sediments collected behind the dam; the Wrights noted that "the area has changed a lot over the last twenty or thirty years"
- Sensitivity rating is Very High and geomorphic rating is Fair

Table 10. Tyler Branch Reach M14 Projects and Practices Table

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M14A M14B M14C	Protect river corridor	High Low Moderate	Moderate Low Moderate	Y	M14AValley walls highly erodible, prone to mass failures and gullying M14B dam, falls: aesthetic and historic value M14C prone to channel avulsions and rapid lateral migration; attenuation asset
M14C	Plant stream buffer; fencing	Low	Low	Y	Cows have access to stream but low impacts apparent; aggrading, rapid planform change
M14B	Remove existing dam	Low	High	N	Removal of dam would create sediment continuity; important to downstream equilibrium, but not fish passage (waterfalls downstream); possible conflict with current development downstream (Brookside); headcut potential and rapidity of sediment transport after removal would require further assessment

6.1.3 Preliminary project identification: Reach M15 – Tyler Branch mainstem/Cold Hollow Brook from approximately 1000 feet upstream of the East Bakersfield Rd. bridge (near Horseshoe Circle-Enosburgh Mtn. Rd. junction) to confluence with unnamed tributary downslope of Babbling Brook Rd., roughly 4500 feet upstream

Reach M15, not segmented for Phase 2 assessment, comprises roughly 3645 feet of the Tyler Branch mainstem and/or Cold Hollow Brook; the confluence of these appears to have significantly shifted over time and appears in either reach M14 or M15 depending on the time period. The reach is located on a dynamic alluvial fan collecting sediments from steep Cold Hollow Mountain drainages to both the southeast and east, and significant differences appear in streams mapped in the area during different time periods. It is conceivable that historically the confluence was physically altered by upstream diversion, to the east of Enosburgh Mtn. Road. Topographic maps from 1925 and 1953 indicate the stream that joins at the confluence of Cold Hollow Brook was located along the east side of Enosburgh Mtn. Rd. and entered the Tyler Branch just above the old mill pond in what was assessed in 2008 as segment M14C (a portion of the 1925 topographic map is included as Fig. 14 with discussion in Sec 5.1.1, Watershed-scale hydrologic alterations, of this report).

In contrast, USGS topographic maps from 1986 and the Vermont Hydrography dataset, used for 2003 Phase 1 assessment of the Tyler Branch watershed, indicate the confluence of the Tyler Branch and Cold Hollow Brook in similar locations further upstream in reach M15 (Fig. 34, next page), confirmed as the present location during 2008 fieldwork. If the stream was indeed diverted (possibly to supply the mill pond), this may have increased flow inputs to the stream without the full attenuation of flow and sediments that would have occurred further upstream on the alluvial fan, where the stream course appears to migrate frequently through accumulated sediments, diffusing stream power both through frequent planform and meander pattern changes as well as the work of moving these accumulated sediments.

Maps from different eras indicate changes in the upstream portion of the reach near the M16 reach break as well (Fig. 34), likely related to the type of rapid lateral migrations and channel avulsions that were observed during 2008 fieldwork. Fieldwork found a very recent change in the confluence of the tributary near the M16 reach break due to the mainstem avulsing and the tributary using the avulsed channel as its own channel (Fig. 33); other portions of this reach showed multiple location/ planform changes as well. With coarse substrates currently limiting planform adjustments and widening, indications are that the stream will utilize much of the valley over time, especially when a flood chute or tributary is captured. This appears to happen primarily in large flood events, with the stream potentially occupying its new location for decades before a similar event occurs.

Figure 33. Dynamic nature of reach M15 is reflected in the recent change of a tributary confluence near the M16 reach break, which occurred when the mainstream avulsed (right) and the tributary captured part of the flow and used some of the avulsed channel as its own channel (left).

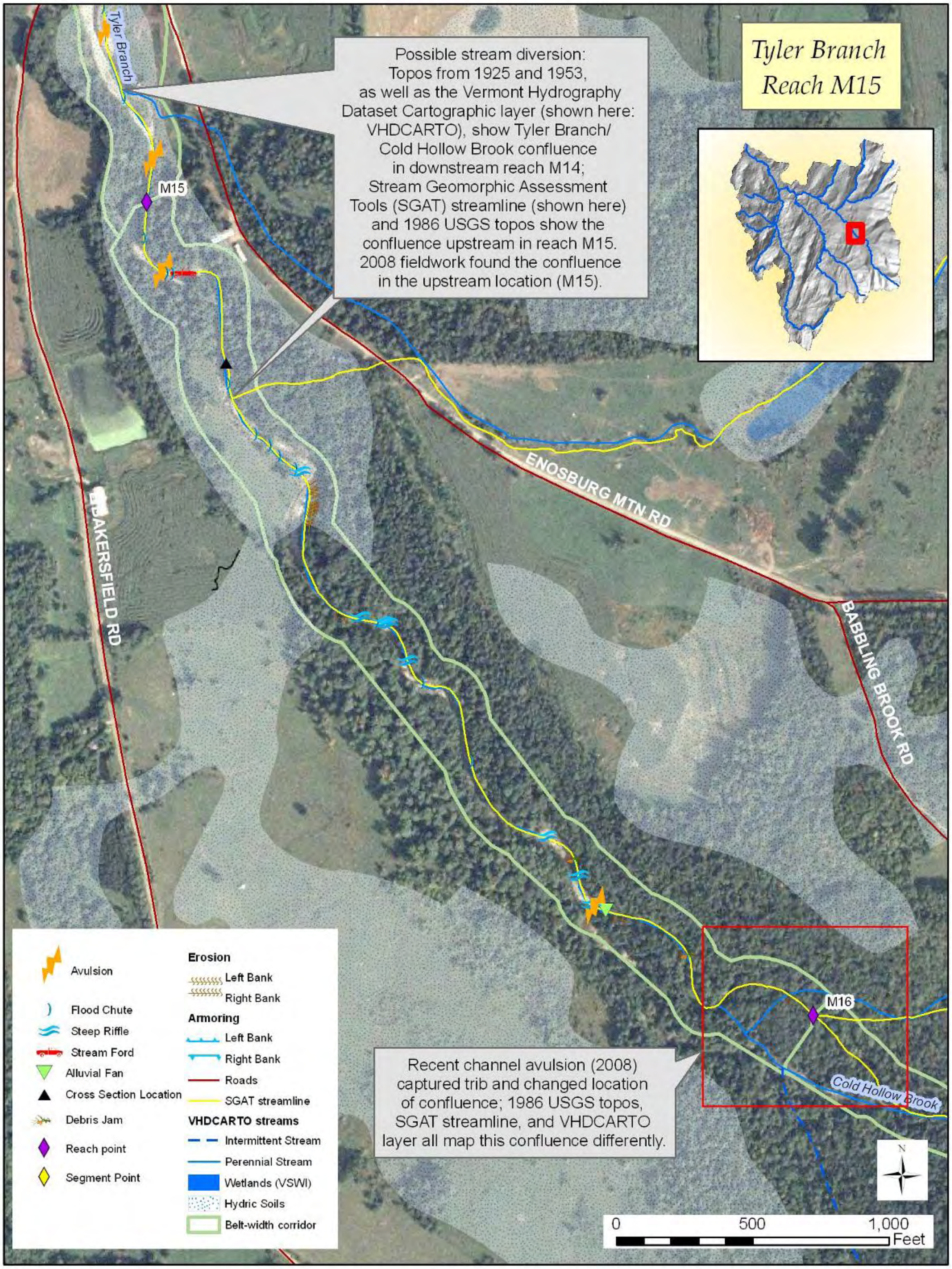


Figure 34. Tyler Branch mainstem/ Cold Hollow Brook reach M15 map.

Distinguishing characteristics for reach M15 included:

- C stream with a gravel-dominated substrate and a slope (~1.9%) approaching the transition to a 'b' subslope
- Slope gradient and relatively coarse substrate contribute to the channel remaining in one place for a period of time after major flood events, rather than more frequent migration and braiding that might appear in a D type stream
- Planebed bedform likely due to aggradation rather than reference conditions
- Buffers 0-25 ft on small portions of both banks in downstream third of the reach
- Multiple flood chutes and channel avulsions, plus changes in tributary confluence locations in upstream portions of reach, indicate stream will migrate across most of the valley over time
- Confluence of Tyler Branch/ Cold Hollow Brook may have been historically altered to supply old mill pond in reach M14; confluence currently in this reach, permitting more flow and sediment attenuation before reaching dam area
- Stage III channel evolution is primarily planform change and still stabilizing after changes related to 2008 flooding
- Sensitivity rating is High and geomorphic rating is Good

Table 11. Tyler Branch Reach M15 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M15-0	Protect river corridor	Moderate	Moderate	Y	Alluvial fan area is an attenuation asset, currently has few conflicts
M15-0	Plant stream buffer; fencing	Low	Low	Y	Cows have access to stream but few impacts apparent; aggradation, rapid planform change make planting challenging; fencing and natural regeneration may be better option

6.1.4 Preliminary project identification: Reach T1.13 – The Branch, from first bridge on East Bakersfield Road east of Bakersfield village to approximately 900 feet upstream of Barber Hill Lane (private road off King Hill Road).

Reach T1.13 is 4,317 feet long and was segmented for Phase 2 assessment. Segments A, B and C are 1453, 1471, and 1392 feet long, respectively. Phase 1 characterized this reach as having a Very Broad valley and an E-type stream with a riffle-pool bedform and a sand substrate. All three segments fit this initial description, although segment B has widened almost to the point of a stream type departure to a C-type stream. Segment B also has a gravel, rather than a sand, bed. Soil maps show that the greater part of this very broad valley is underlain by hydric soils Fig. 36, next page). This reach provides important attenuation assets. Agricultural use, both for pasture and crop land, dominates the stream valley.

T1.13A (1,453 ft) is a highly sinuous stream with an alder buffer and some beaver impacts. The right corridor is used for agriculture and some ditching to facilitate drainage to the stream is in evidence. Key features include:

- Dominant buffer vegetation on the right bank and sub-dominant on the left bank is 0-25 ft. The right bank has almost no buffer and the left buffer is dominated by alder.
- There is almost no development or encroachment on this segment.
- Agricultural pasture land is found in the right corridor area but animals are fenced out of the stream channel.
- The stream is in stage I. Flood plain access is still available and there was only very limited evidence of incision. Moderate planform adjustments are related to beaver damming activity.
- Substrate is sand, sensitivity rating is High, and geomorphic rating is Good.

T1.13B (1,471 ft) is a more impacted section of stream where pastured animals have been allowed access to the stream channel (Fig. 35). Key features include:

- Dominant buffer vegetation on the left bank is 0-25 ft. There is a total of approximately 880 feet of stream bank with a buffer < 25 ft.
- There is no development or encroachment on this segment.
- Erosion is somewhat common; being found along 10-20% of both banks.
- Armoring is found on 10% of the left bank.
- A bridge constriction is found mid-segment.
- More than 20% of the segment has been straightened.
- The stream is in stage III, with historic incision followed by widening and aggradation. Cow access to stream has exacerbated widening; beaver activity augments planform adjustments
- Substrate is gravel, sensitivity rating is Very High, and geomorphic rating is Fair

Figure 35: Reach T1.13 segment B is accessible to pastured animals, reducing buffer and causing some bank erosion.

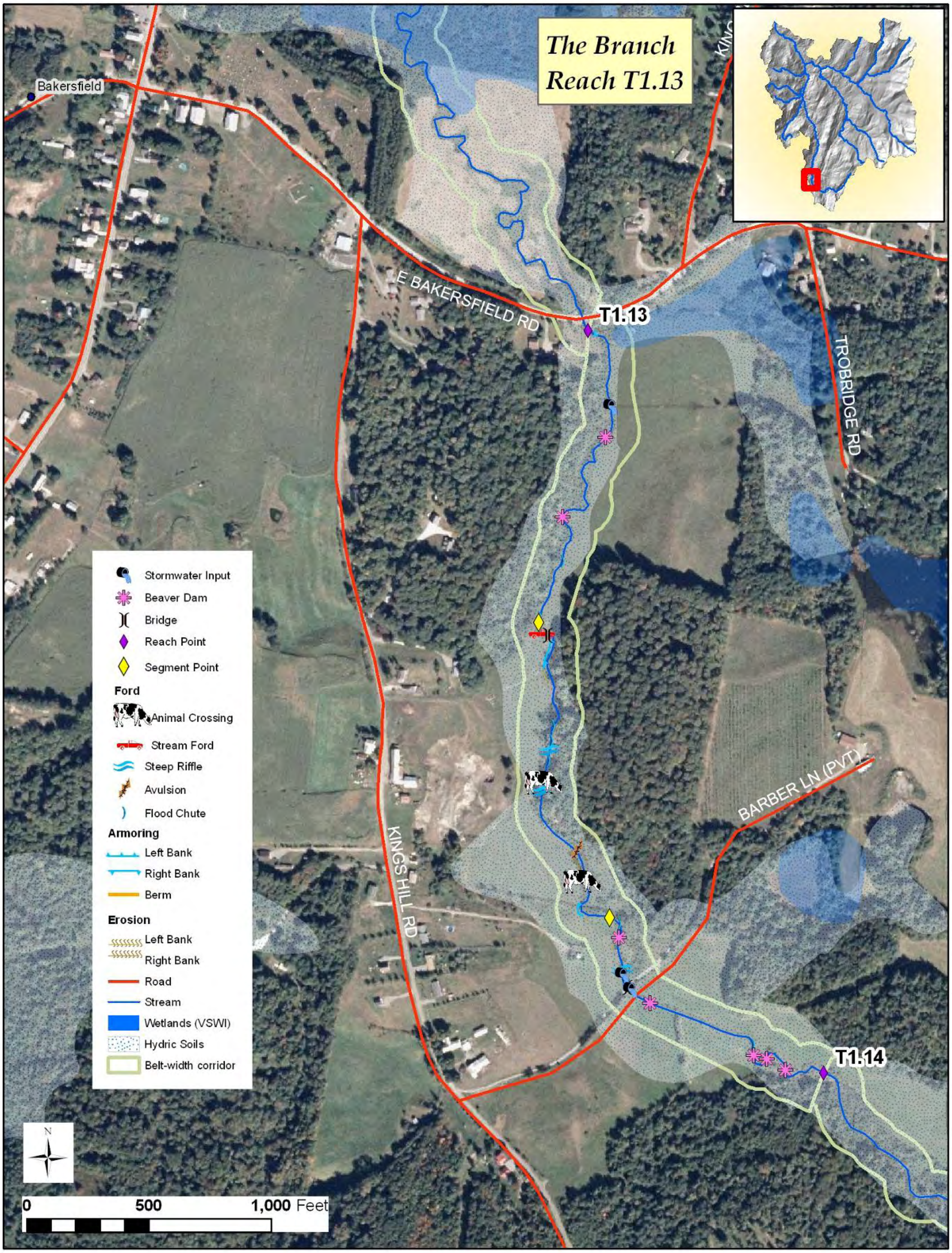


Figure 36: The Branch reach T1.13 map.

Segment T1.13C (1,392 ft) is a mixture of sinuous, beaver impacted stream (upper and lower portion) and a section of straightened stream mid-segment. Adjacent fields on the left bank have the appearance of having been used for agricultural but are now abandoned for that use. The right bank still has active agriculture. Key features include:

- Dominant buffer vegetation on the right bank is 0-25 ft with more than 50% having a buffer less than 25 ft.
- Straightening has impacted >40% of the segment.
- There is almost no development or encroachment on this segment.
- There is a moderate amount of aggradation in this segment, with 5 mid-channel bars, 3 side bars, and 1 steep riffle mapped.
- There is a bridge in this segment that is a channel constriction.
- The stream is in stage I. Flood plain access is still available and there was only very limited evidence of incision. Moderate planform adjustments are related to beaver damming activity.
- Substrate is sand, sensitivity rating is High, and geomorphic rating is Good

Figure 37: Segment T1.13C has been straightened in this mid-section of the segment. The narrow alder buffer is common along this segment and along the entire reach.

Table 12. The Branch Reach T1.13 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.13 A T1.13 B T1.13 C	Protect river corridor	High High High	Moderate Moderate Moderate	Y	Valuable attenuation asset upstream of road crossings. Development threat reduced: Bakersfield setbacks.
T1.13 A T1.13 B T1.13 C	Re-establish buffers, fence animals out of stream buffer area.	High	Moderate	Y	Stream banks somewhat destabilized by pasture use and insufficient buffering.
T1.13 B T1.13 C	Replace Existing Bridge Structures	Low	Low	Y	When bridges are due to be replaced, replace them with structures that do not constrict stream channel.

6.1.5 Preliminary project identification: Reach T1.15 – The Branch, from Waterville Mountain Road continuing upstream ~4600 feet to beaver pond below Checkerberry Ledge, near the Bakersfield/Waterville town line

Reach T1.15 is roughly 4620 feet long and was classified in Phase 1 assessment as an A-type cascade stream with a Very Broad valley confinement. This somewhat anomalous classification is primarily due to a much broader valley in the downstream portion of the reach than in the upper portions, and the reach was segmented during Phase 2 assessment into three subreaches, indicating different stream types, of 890 feet, 1383 feet, and 2346 feet. Hydric soils are found within the stream corridor in the bottom third of the reach, and there are intact beaver dams in that portion of the reach and just upstream of this reach, in reach T1.16 (Fig. 38). With the exception of herbaceous wetlands around the beaver pond at the downstream end of the reach, most of the reach is well forested. There appear to be unusual 'potholes', glacial-related geologic formations of unclear origin in the uplands vicinity of the upstream end of the reach. These are currently being investigated (http://www.uvm.edu/~geology/community/Champlain_thrust.pdf), another part of the fascinatingly complex geologic tapestry of this watershed.

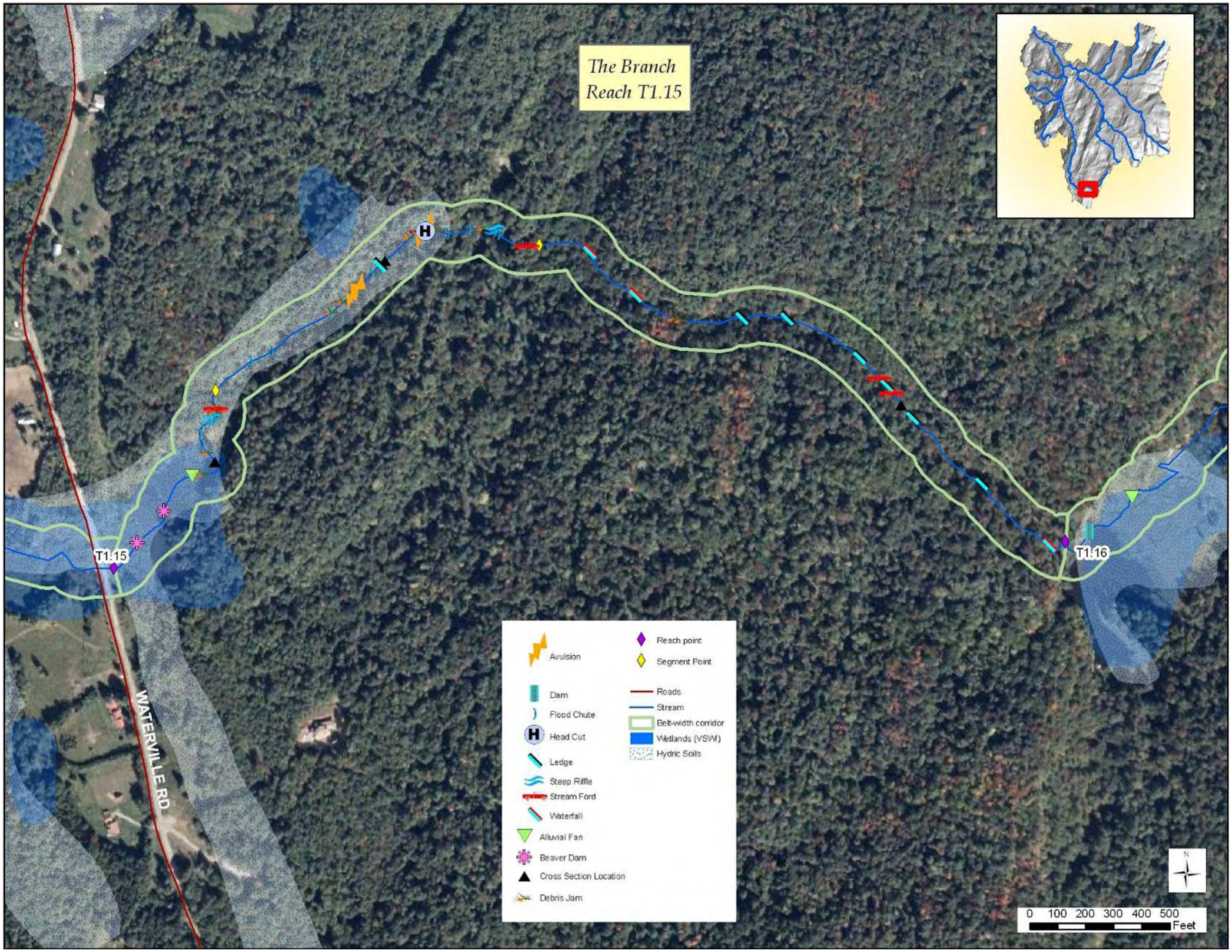


Figure 38. The Branch reach T1.15 map.

Segment T1.15A is an E-type stream in a Very Broad valley dominated by hydric soils, with a riffle-pool bedform and gravel substrate. The downstream end of the segment, abutting Waterville Mountain Road, is currently impounded by beavers, and upstream portions of the segment show indications of having been impounded at other times. Other distinguishing characteristics included:

- Buffers are >100 feet in width but are composed primarily of wetland herbaceous plants with some shrubs, saplings, and small trees tolerant of flooding
- No road or development encroachment, but there is one logging stream ford in the upstream end of the segment
- The stream is in stage I and is fairly stable; planform changes in the stream channel, both current and historic, occur with building and failure of beaver dams
- Woody debris, although mostly small diameter, plays a significant role in the storage and release of sediments in the channel
- Geomorphic rating is Good, sensitivity rating is High

Segment T1.15B is a C-type stream in a semi-confined valley, with the relatively small channel retaining access to adequate floodplain between the steep valley walls to exhibit a characteristic meandering nature and point bar sediment storage, even though the valley confinement is somewhat unusual for this stream type. Reach T1.15 was included in 2008 Phase 2 assessment in part due to reports of potential impacts to water quality and stream dynamics due to logging operations within the reach, and fieldwork did find significant sediment inputs to the stream from logging roads that crossed the stream (Fig. 39). Gully formation on steep approaches to the stream resulted in significant discharges, but corduroy “brush bridges” still in the channel, along with significant large woody debris further downstream, were playing an important role in storing sediment as it moved downstream. Encouragingly, the impacts from the roads in this area were addressed by the current landowner and several collaborators. Follow-up visits will be scheduled to assess the success of these efforts and any needs for further action (pers. comm., Staci Pomeroy, VT-RMP River Scientist, July 2008; Deb Perry, Northwest Regional Planning Commission Land Use Planner, April 2009).

Figure 39. Gully formation (left) on logging roads in segment T1.15B resulted in significant sediment discharges to the stream (right), but large woody debris downstream and corduroy “brush bridges” still in place retained a lot of sediment and are slowing movement of these sediments. Encouragingly, the landowner and several collaborators stabilized the roads and remediated immediate impacts; follow-up visits are intended.

Key features noted in 2008 for segment T1.15B included:

- Buffers are forested and >100 feet except right at the points of logging crossings
- Seven debris jams were a combination of natural large woody debris inputs and brush used to corduroy the stream crossings during logging operations
- Ten flood chutes, two channel avulsions, and one localized headcut (2.5 feet deep) were largely related to sediment storage and release related to the sediment discharges from the stream crossings, exacerbated by flash flooding impacts in summer 2008 microburst
- Sediment aggradation will be impacting stream dynamics for a while as the sediment is transferred downstream in high flows; large woody debris and the low slope gradient and beaver activity in segment T1.15A will play an important role in attenuating these impacts
- The stream is in stage IV, aggrading and changing planform; dominant substrate is gravel geomorphic condition is Fair, and stream sensitivity is Very High

Segment T1.15C comprises the upstream half of the reach, and since it is the dominant stream type was used as the reference type for the overall reach. This portion of the reach is largely located within a Narrowly Confined valley, with some inclusions of slightly wider floodplain access. There are frequent bedrock outcrops in both the valley walls and a series of waterfalls and ledge grade controls, but the slates that dominate the bedrock material are friable and erodible, and contribute to streambed sediments that are relatively resistant to erosion except under high flows.

Additional distinguishing features for T1.15C included:

- Width to depth ratio at the cross-section of 13.9 is actually more characteristic of an F-type stream , but a ± 2 margin was used to characterize the stream as an A type due to the gorge characteristics and quick-check measures throughout the segment
- Buffers are mixed coniferous and deciduous forest and >100 feet in width; no development, minimal encroachment
- Two bedrock constrictions were noted in the segment, and deposition in these areas (and other areas of the segment) includes sands and gravels from beaver-impacted areas upstream as well as slate cobbles from the friable bedrock in the area
- The stream is in stage I and geomorphic condition is Reference, but stream sensitivity is High due to the friable nature of the bedrock and its contribution to a cobble substrate

Figure 40. Sediment deposition in T1.15C includes gravel and sand from upstream beaver-impacted areas as well as cobbles from the friable slate bedrock in the area.

Table 13. The Branch Reach T1.15 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.15 A T1.15 B T1.15 C	Protect river corridor	High Moderate Low	Low Low Moderate	Y	T1.15A and B Valuable attenuation assets for sediments from logging impacts, encroachment issues minimal; follow up remediation efforts on logging impacts in T1.15B. T1.15C in area of high ecological and aesthetic value.

6.1.6 Preliminary project identification: Reach T1S4.02 – Beaver Meadow Brook (Bakersfield), from the beginning of bedrock grade controls (~ 650 feet downstream of County Road stream crossing that is 0.15 mi southwest of the Bakersfield/Enosburgh town line on Rte.108) to just downstream of a County Road bridge that is ~1.25 miles southwest of the town line on Rte.108

Reach T1S4.02 is 7,427 feet long (1.41 miles) and was segmented twice during the Phase 2 assessment process. Segments are 723, 5,248, and 1,455 feet long respectively. The Phase 1 process characterized this reach as having a Very Broad valley, C-type stream with a riffle-pool bedform, and a sand substrate. Segment T1S4.02 B comprises most of the length of this reach and is the basis of the Phase 1 classification. T1S4.02C holds true to the C-type riffle-pool classification, but has a Narrow valley and a gravel bed. T1S4.02A is characterized by a Narrowly Confined valley and an A-type stream with a step-pool bedform and cobble substrate. Soil maps show that almost all of segment B is dominated by hydric soils and a fair amount of Vermont Significant Wetlands Inventory (VSWI) mapped wetlands. This reach is likely to provide important flow and sediment attenuation assets.

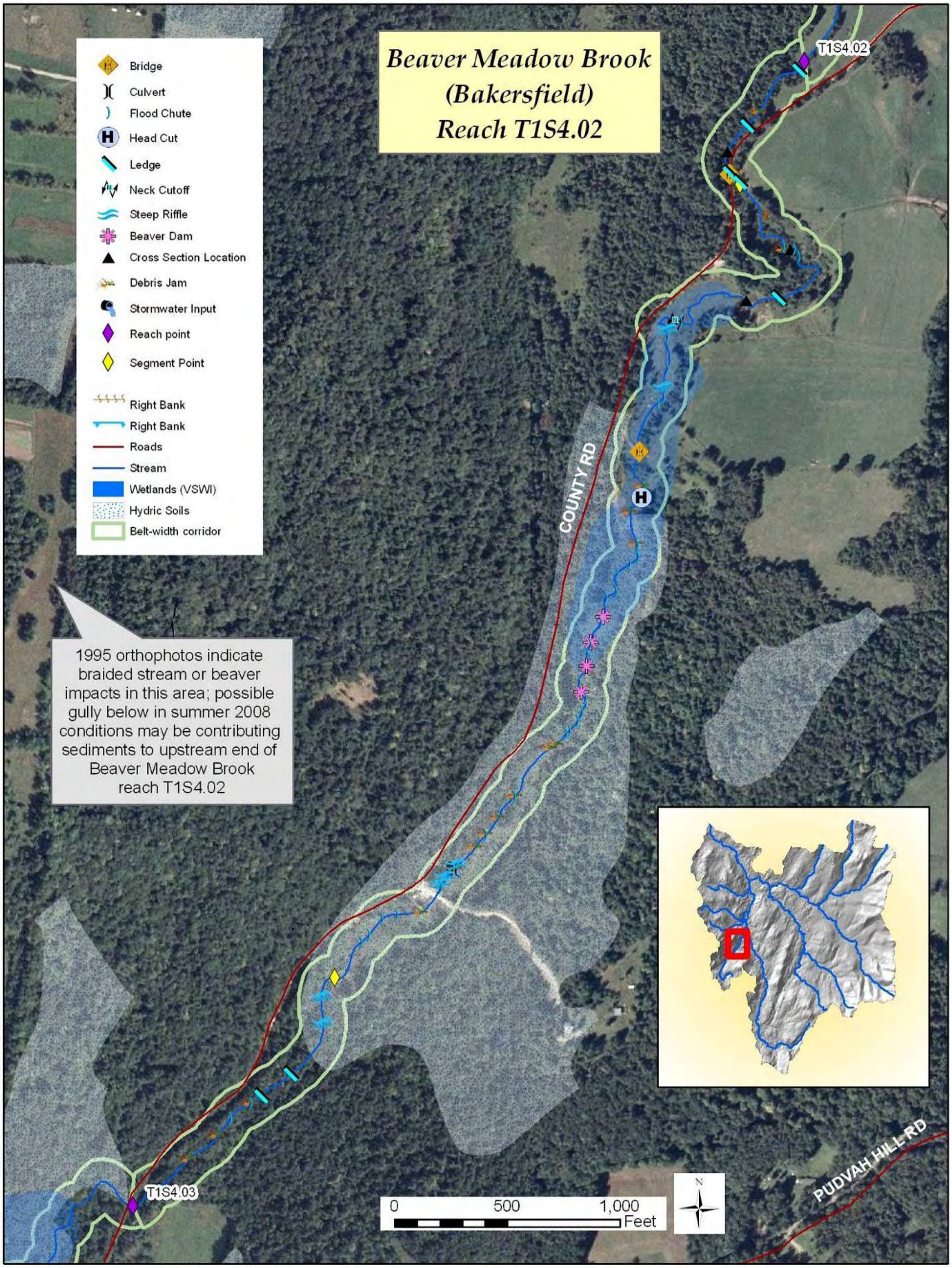


Figure 41: Beaver Meadow Brook (Bakersfield) reach T1S4.02 map.

T1S4.02A (723 ft) is a stable section of stream dominated by bedrock grade controls in a narrowly confined valley. Sensitivity rating is High due to the fact that dominant substrate is cobble. The segment is somewhat variable, with the upper section, where the cross-section was taken, being of lower slope, wider valley, and smaller substrate. Key features include:

- Buffers are forested and generally >50 feet in width.
- Road encroachment is found along >50% of the right corridor.
- There is no development on this segment.
- There is a bridge in this segment that is a channel constriction. The bridge is not substantial and it is possible that a heavy flow would wash it out.
- There are four ledge grade controls in this segment. One measures 16 feet in height.
- The stream is in stage I. Bedrock in the bed and along the banks stabilizes most of this segment.
- Substrate is cobble, sensitivity rating is High, and geomorphic rating is Reference

Figure 42: Beaver Meadow Brook (Bakersfield), reach T1S4.02. Upper segment somewhat wider and shallower slope (left) compared to lower segment dominated by bedrock grade controls (right).

T1S4.02B (5,248 ft) comprises the majority of this reach. It is dominated by wetland that alternates between alder swamp and abandoned beaver meadow. Evidence of beaver activity is common. Key features include:

- Buffers on both sides are >100 ft, but some of the vegetation is made up of beaver meadow grasses/sedges and does not provide shade cover for the stream.
- There is no development and only a small amount of encroachment on this segment.
- There is one ledge grade control feature in this segment measuring 3 feet in height. This grade control is also a channel constriction.
- A culvert constriction is found towards the top of the segment.
- Planform adjustments are common, probably due to beaver activity. Thirty flood chutes and one neck cut off were mapped.

- Aggradation is somewhat common, with 12 mid channel bars, 14 side bars, and 5 steep riffles mapped. A headcut noted in filed assessment was localized and likely to wash out.
- The stream is in stage I. Flood plain access is good. The segment has seen a fair amount of planform adjustment over time, due to periodic beaver activity. Right now beaver activity is only moderate and planform adjustments are similarly moderate and confined to areas of recent beaver activity.
- Substrate is sand, sensitivity rating is High, and geomorphic rating is Good

Figure 43: Beaver Meadow Brook (Bakersfield) segment T1S4.02B alternates between old beaver meadow (left) and alder swamp (right).

T1S4.02C (1,455 ft) is upstream of the hydric soil-wetland area and is characterized by having forested buffers, a Narrow valley, and some bedrock grade control. Key features include:

- Buffers on both sides are >100 ft.
- There is no development and only a small amount of encroachment on this segment.
- There were two ledge grade controls in the segment, both with total heights of 3 feet or less.
- Aggradation is common, with 2 mid channel bars, 12 side bars, 1 diagonal bar, and 2 steep riffles mapped.
- The stream is in stage IId (D evolution model), with aggradation being the dominant process and widening and incision minimal. Bedrock stabilizes the upper portion of the segment, inhibiting both incision and widening. It is suspected that there is a significant source of sediment upstream to explain aggradation in this segment, but the source was not found and did not seem likely to be coming from the forested and alder wetlands in the next reach upstream. Orthophotos from 1995 indicate braiding and possible beaver activity near farm fields to the northwest of T1S4.02C (Fig. 41), and given impacts of 2008 soil saturation and subsequent microburst activity in other assessed portions of the watershed it is possible these sediments may have derived from a gully in this area.
- Substrate is gravel, sensitivity rating is High, and geomorphic rating is Good.

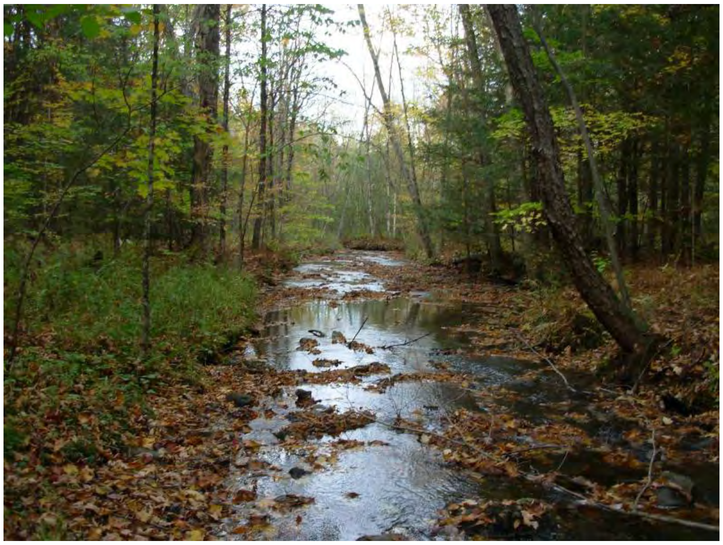


Figure 44: Beaver Meadow Brook (Bakersfield) segment T1S4.02 C shows limited incision and some aggradation.

Table 14. Beaver Meadow Brook (Bakersfield) Reach T1S4.02 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1S4.02 A T1S4.02 B T1S4.02 C	Protect river corridor	Low Moderate Moderate	Low Low Low	Y	Valuable attenuation asset upstream of road crossings. Segment B provides attenuation assets, Segment C shows some channel instabilities.
T1S4.02 B	Re-establish buffers	Low	Low	Y	Beaver meadow areas are not adequately buffered.
T1S4.02 A T1S4.02 B	Replace Existing Bridge and culvert Structures	Moderate High	Low Moderate	Y	Bridge in T1S4.02A liable to be damaged in a flood. Culvert in T1S4.02B should be sized to match channel width.

6.1.7 Preliminary project identification: Reach T2.01 – Bogue Branch from confluence with Tyler Branch to 1.24 miles upstream, at upstream end of agricultural land use on the left bank beneath 1305 Bogue Rd.

Bogue Branch reach T2.01 is 6,539 feet long (1.24 miles) and was segmented twice during the Phase 2 assessment process. Segments are 624, 1,264, and 4,650 feet long respectively. The Phase 1 process characterized this reach as having a Broad valley, a C-type stream with a riffle-pool bedform, and a cobble substrate. T2.01A and T2.01C hold true to the C-type stream, but segment A has a Narrow valley and planebed bedform, and segment C has a gravel substrate. T2.01B was classified as a subreach due to a Narrowly Confined valley and a reference F-type stream with cascade bedform. Soil maps show that portions of the valley for segment C have hydric soils and/or Vermont Significant Wetland Inventory wetland areas. This reach is likely to provide important attenuation assets.

T2.01A (624 ft) is a short section of stream that runs along the western edge of a valley that spreads from narrow to very broad as it joins the Tyler Branch mainstem. It is conceivable that this segment is an alluvial fan beneath the bedrock gorge of segment T2.01B, but the stream is located against the left valley wall and may have been maintained that way over time; if the area is an alluvial fan, that fact is masked by current land use and cover. The valley off the right bank is used for pasture and buffers on this side are minimal. Key features include:

- Dominant buffer on the right bank is 0-25 ft, with approximately 390 feet having a buffer of less than 25 ft.
- Cows are allowed access to this section of stream.
- There is no development on this segment.
- Farm road encroachment is present along 40% of the right bank.
- The reach has been straightened for >75% of its length.
- There is one mass failure, and erosion is somewhat common; occurring along 10% of the segment's length.
- The stream is in stage II, with incision being the dominant process.
- Substrate is cobble, sensitivity rating is High, and geomorphic rating is Fair

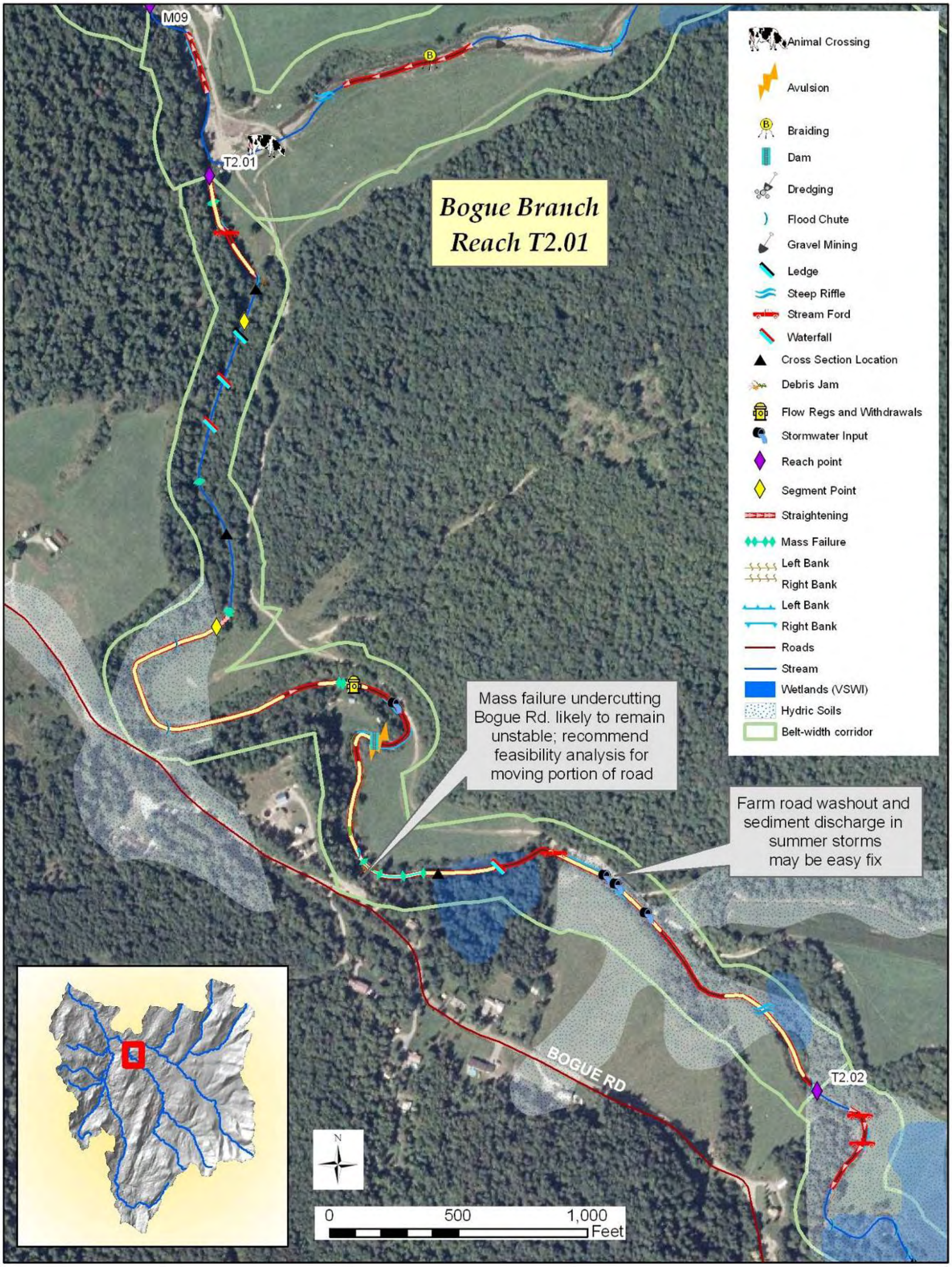


Figure 45: Bogue Branch reach T2.01 map.

T2.01B (1,264 ft) is a section of stream dominated by a forested buffer, narrowly confined valley, and several ledge grade controls. The stream type varied between F and A types. Steep bedrock cascade sections are more A-like, but in between ledges widening has occurred and the segment was classified overall as an F-type stream. Key features for this segment include:

- Buffers on both sides are >100 ft.
- There is no development on this segment.
- Road encroachment affects approximately 50% of the right bank corridor.
- There were three ledge grade controls in the segment, two of which measure greater than 10 feet in total height. One of these also constitutes a channel constriction.
- The stream is in stage I. Bedrock stabilizes this segment, inhibiting both incision and widening. Some widening occurs between bedrock ledges.
- Substrate is cobble, sensitivity rating is Very Low, and geomorphic rating is Reference.

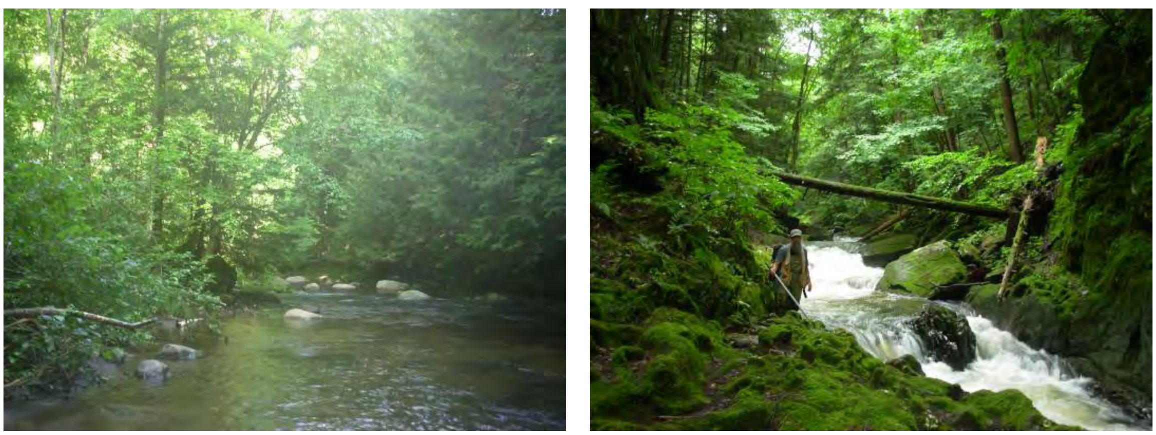


Figure 46: Bogue Branch reach T2.01segment B has both F-type (left) and A-type stream.

T2.01C (4,650 ft) is the dominant segment for the reach. It is characterized by frequent corridor encroachments and significant channel straightening. This portion of the reach has significant attenuation assets. Key features include:

- Dominant buffer on the right bank and subdominant buffer on the left bank is 0-25 feet, with a total of >3,700 feet of buffer < 25 feet.
- There is a small amount of development present on this segment.
- Road encroachment is found along >50% of one side and occasionally on both sides. Summer 2008 storms washed significant sediments from a farm road into the stream in the middle of the segment (Fig. 47); this may be an easy fix for prevention of future washouts. This is primarily a water quality issue, as the quantity of sediment discharges were not likely to impact stream dynamics significantly.
- The entire segment has been straightened by maintenance in place through land use practices as well as possible ditching in some areas, though this was not confirmed.

- Cow access to the stream is common in mid-segment.
- There is one ledge grade control in the segment and one small human made dam (partially permeable, constructed of large stones and some concrete) that currently impounds a small amount of water for withdrawal and recreational use; it was not clear what the structure may have been originally constructed for. This dam does not appear to be playing a significant role in stream dynamics. The ledge feature measures 9 feet in total height. Two minor bedrock constrictions were also found in this segment.
- Mass failures and bank erosion are significant for this segment. A portion of Bogue Rd. is at risk in mid-segment, and fill appeared to have been dumped on the edge at this point. This area would benefit from further assessment to determine whether relocation of the road might be feasible and more cost-effective than attempts at bank stabilization, which are prone to failure at this point due to likely further bank instability and pressure due to stream processes and channel evolution. Sediment is not reaching the stream at this point.
- Aggradation is common, with 9 mid channel bars, 14 side bars, 1 diagonal bar, and 1 steep riffle mapped.
- T2.01C is in stage II-III, with incision being the dominant process but being followed by widening and aggradation in some portions of the segment.
- Substrate is gravel, sensitivity rating is Very High, and geomorphic rating is Fair.

Figure 47: Bogue Branch, reach T2.01, segment C. A large mass failure is found below Bogue Rd. on the left bank valley wall in mid-segment (left). Summer downpours contributed to sediment inputs to the stream from a farm road off the right bank (right).

Table 15. Bogue Branch Reach T2.01 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T2.01 A T2.01 B T2.01 C	Protect river corridor	High Low High	Moderate Low Moderate	N	T2.01A and T2.01C are valuable attenuation assets upstream of major confluence, reduced functionality due to current land use and straightening; feasibility analysis for Bogue Rd. relocation in T2.01C
T2.01 A T2.01 C	Re-establish buffers, fencing	Moderate Moderate	Low Moderate	Y	Ag land has reduced to minimal buffers, animal, cow access to stream. Low-cost plantings due to lateral instability
T2.01C	Remove dam	Low	Low	Y	Low, permeable rock dam does not appear to play a significant role in stream dynamics

6.1.8 Preliminary project identification: Reach T2.02 – Bogue Branch from upstream end of agricultural land use on the left bank beneath 1305 Bogue Rd. to ~400 ft downstream of Boston Post Rd. bridge.

Bogue Branch reach T2.02 is 5109 feet long (0.97 miles) and was assessed in Phase 2 as three segments of 1751, 1089, and 2269 feet. Phase 1 stream typing characterized the reach as a C-type riffle-pool stream with a gravel substrate, located in a Broad valley. Segments T2.02A and C retained this classification, but T2.20B was broken out as a B-type stream with a cobble substrate and planebed reference bedform, located in a Narrowly confined valley. Crop and pasture land is located on mapped wetlands in the downstream end of the reach, and hydric soils occupy roughly three quarters of the stream corridor in the overall reach (Fig. 48).

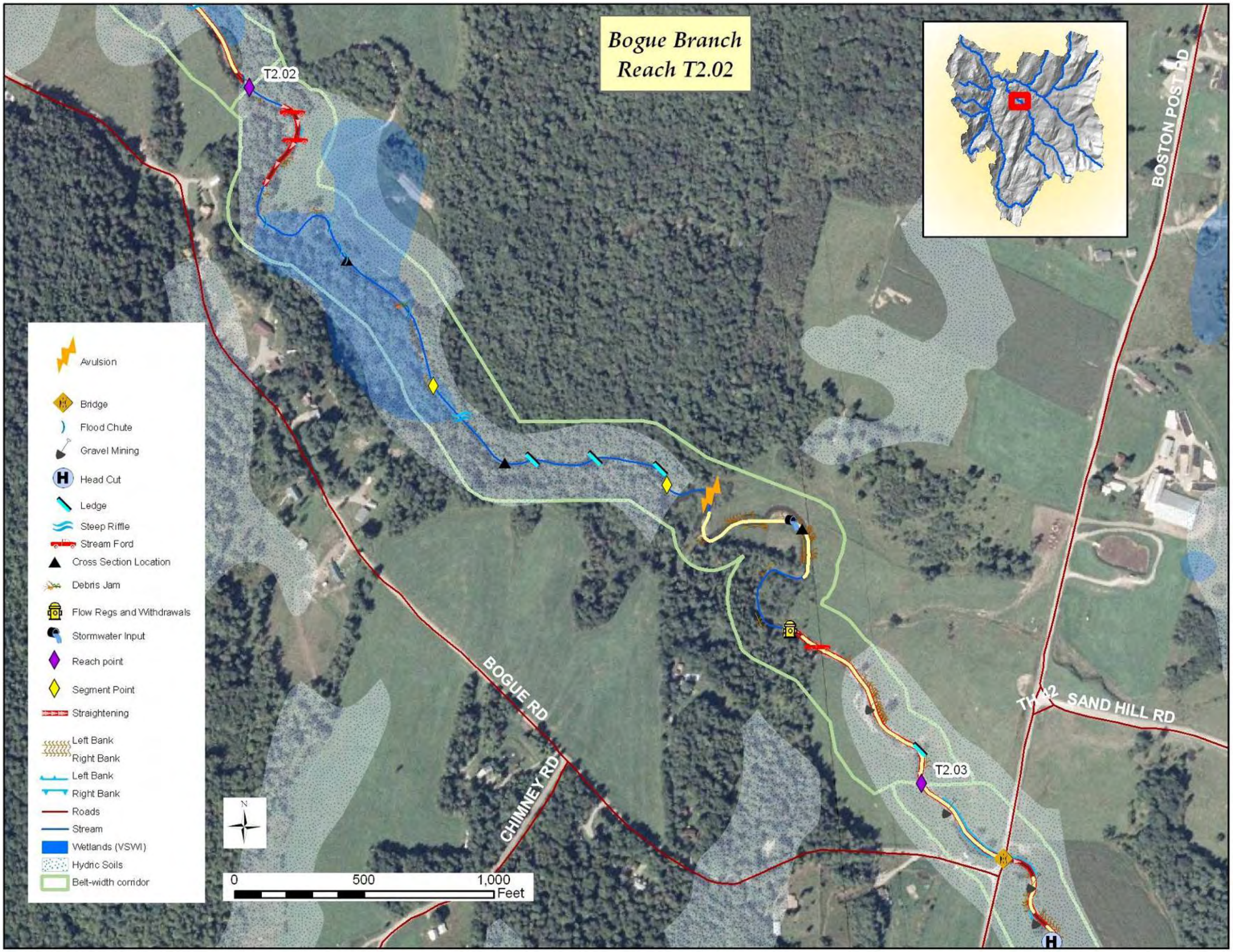


Figure 48. Bogue Branch reach T2.02 map.

Segment T2.02A comprises the downstream 1750 feet of the reach, is a C-type riffle-pool stream situated in a Very Broad portion of the valley, and is bordered on the right bank by agricultural fields that appear to be in a crop/hay/pasture rotation. There were a number of unmaintained stream fords, with a couple of these likely used for infrequent tractor crossings, or possibly crossings for logging. Some of the other crossings appeared to be travelled by ATVs, although no ATVs were observed during the assessment. Distinguishing characteristics included:

- Forested wetland buffer of mixed trees >100 ft in the left bank corridor, 51-100 ft buffer on right bank composed primarily of wetland shrubs and saplings (Fig. 49)
- No development or encroachments, although tractor access is maintained around the fields
- A small amount of erosion was evident, primarily on outsides of meander bends, and a short stretch of riprap is in place on the right bank downstream in the segment
- Straightening of >20% is primarily due to land use practices maintaining the stream in a fixed location over time
- Segment T2.02A is in stage III channel evolution, with historic incision (limited by grade controls in the next segments both downstream and upstream) and minor current widening, aggradation and planform change
- Gravel substrate, Geomorphic condition Good, stream sensitivity Moderate

Segment T2.02B, 1089 feet long, is a bedrock-controlled portion of the reach. This B-type stream with interspersed ledge grade controls was assessed as a planebed stream by reference. Although the ~1.4% slope seems low for a reference planebed, the valley is Narrowly Confined, increasing streampower, and most fine sediments appear to be getting flushed through regularly; coarser sediments are widely and evenly dispersed, so neither riffles nor steps are setting up (Fig. 49). It appeared the segment may be shallow to bedrock throughout. Additional features of note included:

- No development or encroachments
- Coarse sediments common in the reach, with boulders accounting for 22% of the cross-section pebble count
- Well-forested buffers >100 feet wide on both banks
- Tributary rejuvenation noted in the reach was triggered by stormwater inputs from ag fields well back away from the stream rather than incision within the segment
- Cobble dominated substrate, Stage I channel evolution with minor episodic widening; geomorphic condition Good, sensitivity Moderate

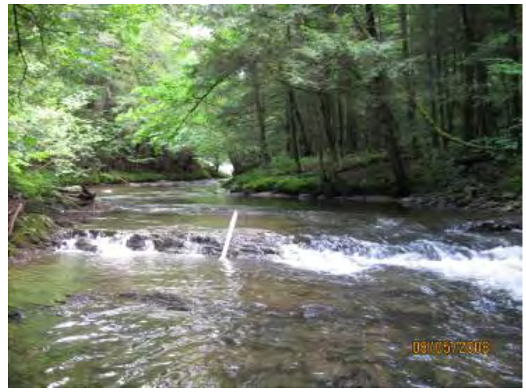


Figure 49. Bogue Branch T2.02A (left) is buffered by forested wetland, shrub/sapling and herbaceous vegetation. T2.02B (right) is a bedrock-controlled, B-type planebed section of the stream.

Segment T2.02C is a C-type riffle-pool stream in a Very Broad valley, and is primarily cow pasture; cattle have free access to the stream. The area appears to be ditched for drainage but not tiled. Key features included:

- No development or encroachment
- Cows have free access to the stream except in herbaceous wetland areas
- Banks are sandy, and there is erosion along 5-20% of the left bank and >20% of the right bank
- A little over half of the segment on both banks has no woody buffers
- Subdominant buffer on the left bank is foreted and >100 feet in width; right bank subdominant buffer is 51-100 feet and is primarily facultative wetland herbaceous
- Tributary rejuvenation noted for the segment was due to a nickpoint at the mouth of a field ditch and may have been related to recent intense storms rather than the limited amount of incision noted in this segment (Fig. 50)
- Small-scale gravel removal in the upstream portion of the segment appeared relatively recent and was part of the basis for straightening noted in the segment (Fig. 50)

Figure 50. Nickpoint in a field ditch entering Bogue Branch T2.02C (left) may have been related to recent intense storms rather than the limited amount of stream incision noted in the segment. Gravel removal in the upstream portion of the segment (right) was part of the basis of straightening noted for the segment.

Table 16. Bogue Branch Reach T2.02 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T2.02 A T2.02 B T2.02 C	Protect river corridor	Moderate Low High	Moderate Low Moderate	Y	Moderate sensitivity in T2.02A and B, gravel removal in C indicate evolution may be slow
T2.02 C	Plant buffers Fencing	High	Moderate	Y	Ag land has reduced to minimal buffers, cow access to stream. Low-cost plantings due to lateral instability

6.1.9 Preliminary project identification: Reach T2.03 – Bogue Branch from just downstream of the Boston Post Rd. bridge at Bogue Rd. upstream to farm road stream crossing just west of the garlic farm on Witchcat Rd.

Bogue Branch reach T2.03 covers 4632 feet (0.88 mi.) and was typed in Phase 1 as a C-type riffle-pool stream located in a Very broad valley. The reach was broken into three segments for Phase 2 assessment, based primarily on gravel mining activities in portions of the reach and changes in buffer conditions along the reach. All three segments were C-type riffle pool streams with gravel substrates, and were 1926, 1394 and 1311 feet in length. Hydric soils are common along the entire corridor, and a long, linear Vermont Significant Wetlands Inventory mapped wetland additionally covers most of what is not considered hydric in the corridor.

There was an excavator from Gervais Farm in the stream at the beginning of the T2.03A assessment. Numerous areas had been excavated along the reach over time, with stockpiled gravel next to the stream in a few areas (Fig. 51).

Figure 51. Gravel removed from Bogue Branch segment T2.03A was stockpiled along the banks in a few areas.

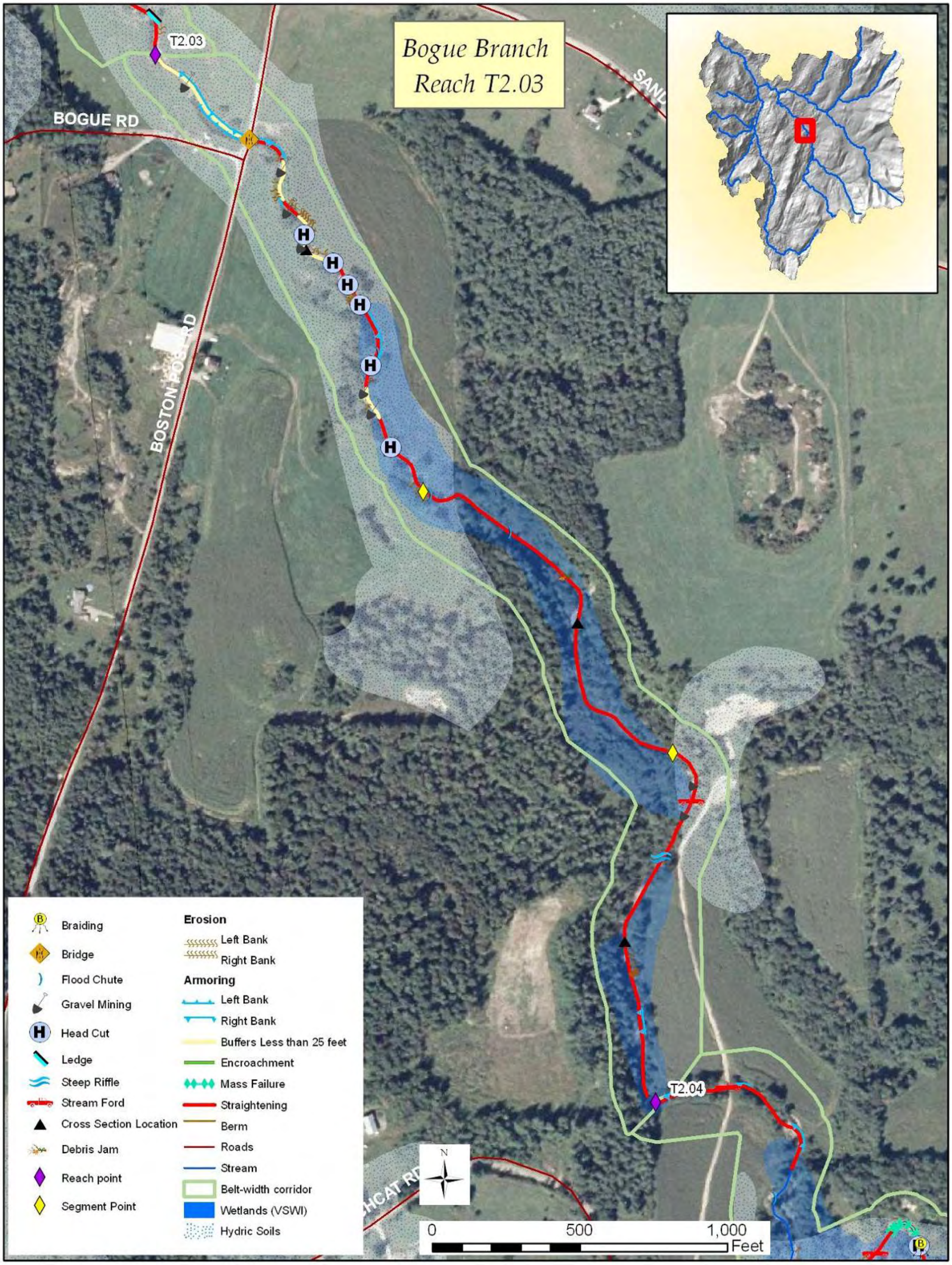


Figure 52. Reach map for Bogue Branch reach T2.03.

Headcuts noted in segment T2.03A were associated with areas of gravel removal, and appear to wash out quickly through new aggradation. None of these nickpoints appeared to be migrating upstream, but the segment did appear to be incised (ratio 1.9). Planform was difficult to assess, as the stream frequently migrates laterally in response to removals, but it was hard to know how fleeting these shifts were. Stream Alteration Engineer Chris Brunelle visited this site and felt that the removals were within permitted uses (pers. comm., VT-RMP River Scientist Staci Pomeroy , September 2008).

Additional distinguishing characteristics of segment T2.03A included:

- Road encroachment on one side of the stream along roughly 10% of the segment
- Erosion on 10 – 15% of the segment on each side
- Riprap on ~10% if the left bank nearly 40% of the right bank.
- Dominant buffers were less than 25 feet on both banks
- The stream was noted as stage III, primarily widening, but this was difficult to read due to the levels of disruption to channel evolution
- Substrate is gravel, geomorphic condition rated Poor and sensitivity is Very High
- Unconfined source and transport sediment regime due to concurrent incision and widening
- Bridge at Boston Post Rd. is sized at 84% of reference bankfull width; further slight reduction due to angle of alignment) and is both a channel and floodprone constriction, but channel avulsion would continue downstream; current problems minimal for structure

T2.03B, 1394 feet long, was segmented due to a lack of gravel removal as well as better bank and buffer conditions. A series of terraces were observed off the left bank in particular and were perceived as an indication of successive losses of floodplain over time. It was in this segment that notes began to be recorded indicating impacts (bed downcutting) from a dam located in upstream reach T2.05.

Key features for T2.03B included:

- No encroachments or development in the corridor
- Buffers of >100 feet were dominantly composed of shrubs and saplings, with young but larger trees occupying the terraces further back from the stream
- Tributary rejuvenation noted in the reach: With recent intense storm events evident in watershed, it is likley that this was partly triggered by heavy stormwater in the head of the tributary, but multiple terraces evident off the left bank, a historic mill dam located upstream, recent gravel removal upstream and downstream of this segment, and extensive straightening and recent channel avulsions in the next reach upstream led to assessment as both historic and active incisional processes in this segment and thus increase the likelihood that the tributary rejuvenation was at least partly related to lowering of the tributary bed elevation in response to incision on the mainstem.

- One stream ford in the downstream end of the segment appeared to receive only occasional use
- Most of T2.03B appears to be maintained against the valley wall and was noted as straightened due to lack of meanders, though there was no evidence of armoring or other revetments
- Stage II channel evolution but also showing signs of aggradation
- Gravel substrate, geomorphic condition Fair, sensitivity Very High

Segment T2.03C, 1311 feet long, has crop land (corn in 2008) along most of the right bank corridor. Key features include:

- Recent small scale gravel removal on downstream end, possibly used for farm road maintenance. Farm road off right bank was significantly extended/improved between time of 1998 orthos and 2003 NAIP aerial photography, and a small sand/gravel pit appears to have been opened off the downstream right bank of this segment to provide construction material (Fig. 53); not clear if or how much material was obtained from the stream for this effort. Bedrock outcrops in upper portion of the segment would likely hamper gravel removal in the upstream area.
- Buffers, though diminished on right bank, are never less than 25 feet
- LB bedrock outcrops in the upstream portion are augmented by toe stabilization on the RB in the same area, and the 100 feet of erosion within this segment occurs just downstream of this stabilization.
- Riffles, though apparently sedimented, did not appear stable; transitory, small substrate. Deposits could be from recent inputs due to intense storms (ditches and stormwater inputs contributing sediments) or that bed is experiencing progressive fining as coarser materials (coarse gravel and small cobble) are removed at several extraction points downstream.
- Flow regulation upstream is Johnson Mill dam (mill buildings now gone), at T2.05 reach break.

Figure 53. Recent gravel removal at downstream end of segment T2.03C (left) is very close to a pit (right) that appears to have been opened sometime between 1995 and 2003, and was likely used to significantly upgrade the road that runs along the right bank of segment T2.03C.

Table 17. Bogue Branch Reach T2.03 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T2.03 A T2.03 B T2.03 C	Protect river corridor	High High High	High Moderate High	N	Explore options for channel management easement options in segs A and C; in C focus on areas downstream of bedrock outcrops in upstream portion of segment. All three segments have potential as attenuation assets; gravel removal currently constrains vertical channel evolution, intensive ag use may present lateral constraints. Segment A would particularly need augmentation of buffers as well
T2.03 A T2.03 C	Establish and/or augment buffers	High High	High High	Y	Mixed-cost plantings; higher value stock for augmentation, low-cost for establishment: lateral instability and likely channel evolution (widening)
T2.03A	Replace bridge	Low	Moderate	Y	Contributes primarily to straightening, structural problems, deposition minimal

6.1.10 Preliminary project identification: Reach T2.04 – Bogue Branch from farm road crossing west of garlic farm on Witchcat Rd. to Johnson Mill dam, upstream of Witchcat Rd. and west of Joyal Rd. intersection

Bogue Branch reach T2.04 is 4627 (0.88 mi.) feet long and was classified in Phase 1 as an E-type riffle-pool stream with a gravel substrate, situated in a Very Broad valley. The reach is experiencing significant adjustments that appear related to primarily historical impacts from flow regulation at the Johnson Mill dam in the next reach upstream and extensive straightening either initiated or exacerbated in the 1990s. Phase 2 assessed the stream in two segments of 2846 and 1781 feet, due primarily to differences in channel dimensions. Both segments were typed in Phase 2 as C-type riffle-pool streams in Very Broad valleys, a stream type departure from their reference E-type. Upstream segment T2.04B appears a bit more incised and is just barely maintaining access to floodplain off the left bank in flood flows (2x bankfull depth).

Segment T2.04A is bordered by relatively intensive agricultural use along most of the left bank corridor and much of the right bank corridor as well, with cultivated cropland (corn in 2008; Gervais Farm) on both sides of the stream in the downstream portion and Witchcat Farm growing garlic in the left bank corridor in the upstream half of the segment. This area was heavily impacted during the 1997 and 1998 floods, and the Federal Emergency Management Agency helped fund windrowing and riprapping of roughly 150 feet of the left bank below the Lopes' home and barns at the garlic farm, and Mr. Lopes has augmented this with a gravel berm upstream of the riprap (Fig.54).

Figure 54. FEMA helped fund riprapping of the left bank in segment T2.04A beneath the Lopes' home and barns at Witchcat garlic farm, which has been augmented by windrowing and berm construction upstream.

A short distance upstream of the riprap and berm a mass failure has occurred on the right bank, and upstream of that there is a large sediment plug that has closed the mouth of a former large meander in a wetland area off the right bank (Fig. 55), contributing to a channel avulsion that has significantly shortened the channel length (and thus increased the slope, since the stream no longer crosses the slope gradient through the meander). A pond further east in the valley off the right bank is visible in 2003 color aerial photos, but 1995 black and white orthophotography indicates a meandering stream in this area (Fig. 56).

Figure 55. A large sediment plug has closed the mouth of a former meander through a wetland area in T2.04A, contributing to a channel avulsion that has significantly shortened the channel.

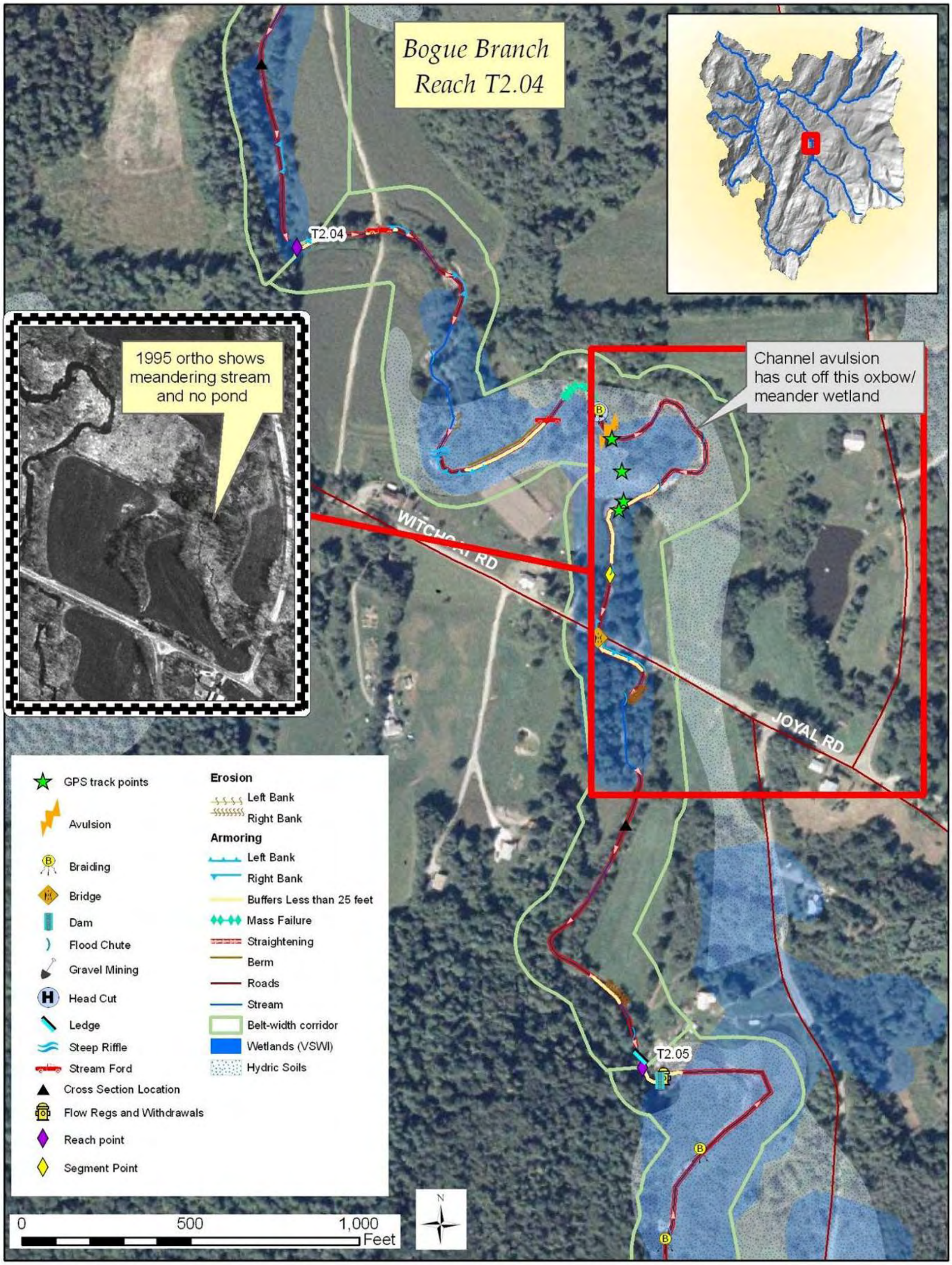


Figure 56. Reach map for Bogue Branch reach T2.04.

While it is not known exactly when the pond was constructed, it does appear that the sediment plug that closed the top of the meander is located at the downstream end of a drainage flowing away from what is now the pond site, giving rise to questions concerning the impacts of the floods on water and sediment discharges arising from the area of the pond. Given the highly sinuous nature of the stream visible in the 1995 orthophotography it is likely that sediments in this area would be very fine, while the gravels that plugged the meander mouth are coarser. A high flow discharge to the point of the meander plug, however, may have contributed to formation of a delta deposit accruing sediments from Bogue Branch as the floodwaters receded. This area was photographed during a flyover in 2009 (pers. comm., VT-RMP River Scientist Staci Pomeroy and NRPC Land Use Planner Deb Perry), and the disconnected meander as well as the drainage from the pond area leading to the sediment plug are clearly visible in one of the photos (Fig. 57).

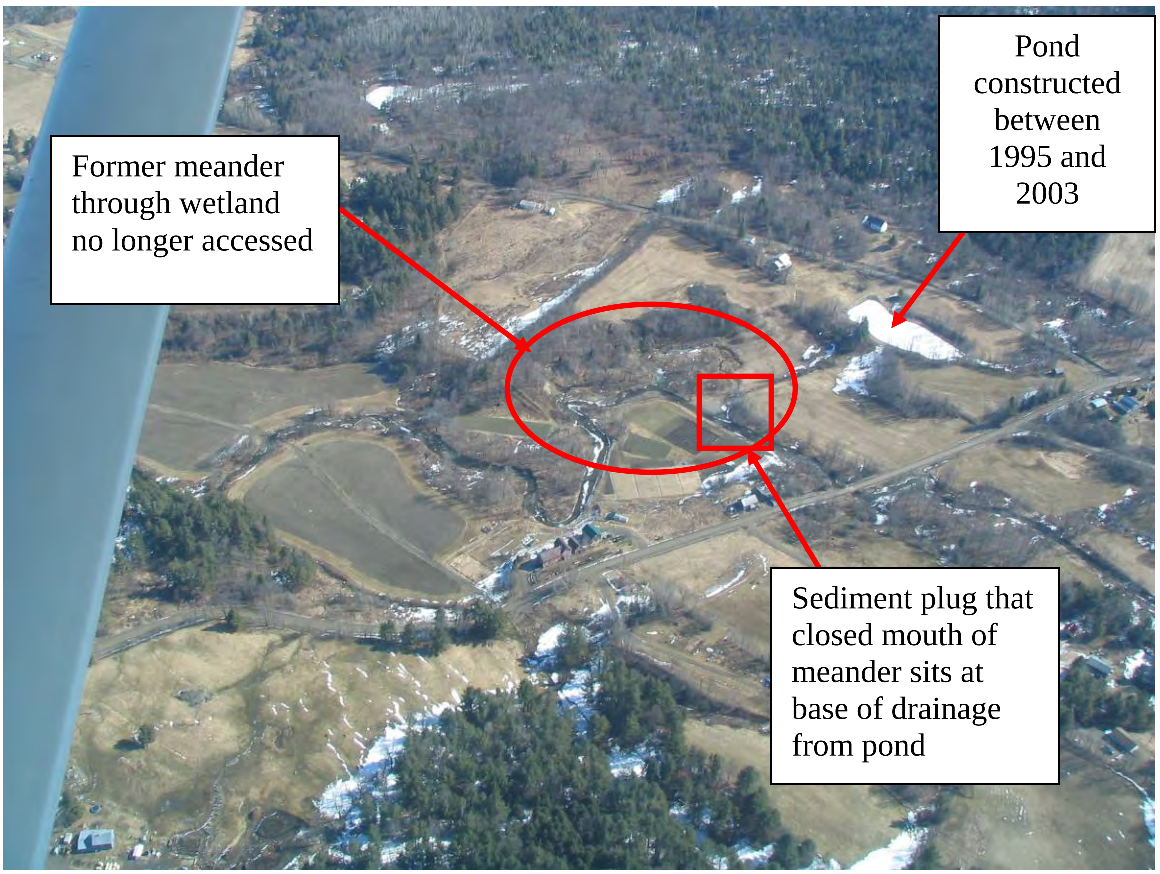


Figure 57. Aerial photo from 2009 flyover at the site of a channel avulsion in segment T2.04A indicates that the sediment plug that closed the mouth of the former meander during a 1997 flood sits at the downstream end of a drainage coming from a pond to the east that was built sometime between 1995 and 2003.

The wetland meander in this area played a valuable role in diffusing stream power in particular, and the shortened, steeper channel now flowing by the garlic farm is likely to be further energized. Sensitivity analysis indicated Very High sensitivity for the stream in this area, indicating good chances for the channel to evolve using its own resources to establish new meanders, and significant deposits are already visible in the channel in aerial photography from the 2008 flyover. An active restoration project to remove gravel from the mouth of the meander might be valuable to restore the attenuation functions of the wetland, but may not be necessary if the stream can accomplish this on its own. An active restoration would also be at high risk for failure if more flooding were to occur before new meanders and buffers were established and stabilized, and project design would need to be based on expected sediment and flow discharges from upstream. These discharges are currently undergoing adjustments themselves, as discussed in the reach descriptions for reaches T2S1.01 – T2S1.04 in Section 6.1 of this report. Higher priority would thus be given to addressing upstream impacts first, but buffer establishment, augmentation and maintenance would greatly benefit this reach and could be completed independently.

- Key features in T2.04A included:
- Banks and adjacent sideslopes primarily sand and silt (little to no clay, so non-cohesive)
- Two mass failures (30 ft long, 15 ft. high and 120 feet long, 30 feet high)
- Only 2% of the right bank showed erosion, but ~5% of the left bank and 10% of the right bank are armored, with an additional 260 foot berm upstream of the left bank riprap (~10% of the segment)
- Nearly all buffers <50 feet, with ~25% of the left bank and 3% of the right bank buffers <25 feet
- A recent (late 1990s) major channel avulsion that has cut off access to an old meander (see text above)
- A headcut was noted in the segment just downstream of the channel avulsion; while likely to wash out quickly, this nickpoint did appear to indicate effects of heightened stream power
- Nearly the entire segment is straightened, contributing to the E to C stream type departure noted for the segment; both loss of sinuosity and current gravel sediment storage in point bars, likely to widen further before bars develop enough to start narrowing the stream toward E channel dimensions again
- Bar scalping in the area of the sediment plug at the head of the meander; not clear how much of the rest of the segment has recurrent bar scalping as opposed to channel “clean-out” after the 1997 flood
- Two stream fords; the downstream one is a major access to corn fields from Witchcat Rd. (farm road may utilize gravel from stream); the upstream one at the garlic farm accesses hay field; minor additional deposition at these fords.
- Channel evolution stage II, geomorphic condition Poor, stream sensitivity Very High

Segment T2.04B has stretches (along Witchcat Rd. near and just upstream of the bridge, development downstream of the bridge on both sides, and the remains of the old mill building foundations at the Johnson Mill dam at the head of the reach) where human-elevated floodplain encroachments have increased the incision ratio of the stream (~15% of the segment); the stream still maintains access to the floodplain in other areas. Cross-section measurements were taken in an area without the human elevated floodplain and indicated that the stream is still very close to losing access to its historical floodplain in this segment. There is a ledge grade control that limits further downcutting, but further human-elevated encroachments would exacerbate current stream dynamics that contribute to increased stream power impacts passed to downstream reaches.

Characteristic features of segment T2.04B included:

- 15% of the segment with road and development encroachments
- Erosion on 10% of the right bank and an additional 10% riprapped
- Buffers diminished but present (dominant 51-100 feet on left bank, 26-50 ft on right bank); only lacking (25 feet) along Witchcat Rd. and by old Johnson mill
- Johnson Mill dam at head of segment
- Roughly 85% of the segment is straightened
- There is one ledge grade control in the middle of the segment which plays a large role in the stream not losing access to floodplain
- Witchcat Rd. bridge is undersized (55% of reference bankfull channel width), with the effective width reduced to 40% of bankfull channel width by the angle of alignment to the stream. The bridge appears to be fatigued and may pose a safety hazard, and is highly recommended for further assessment regarding possible replacement (Fig. 58). Larger sizing and adjustment of the angle of alignment would benefit both stream dynamics and structure longevity.

Figure 58. Bridge at Witchcat Rd. in segment T2.04B is reduced to 40% of bankfull channel width by the angle of alignment to the stream (left), appears to have possible signs of structural fatigue (right), and is recommended for further assessment regarding possible replacement.

Table 18. Bogue Branch Reach T2.04 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T2.04A T2.04B	Protect corridor	Moderate Low	High Low	N	T2.04A limited development but significant ag use constraints; degree of straightening investments places higher priority on downstream reach for attenuation, upstream reaches for addressing inputs
T2.04A	Plant buffers	High	Moderate	Y	Low-cost plantings due to lateral instability
T2.04A	Restore incised reach to abandoned channel	High	Moderate	N	Removal of sediment plug closing access to former meander; stream may reaccess lower portion of meander on its own; risk of project failure if flooded before stabilized; design dependent on upstream stressors (flow in particular), higher priority on addressing these first

6.1.11 Preliminary project identification: Reach T2.05 – Bogue Branch from Johnson Mill dam, upstream of Witchcat Rd. and west of Joyal Rd. intersection, to upstream end of second hayfield on Witchcat Rd. south of Joyal Rd.

Bogue Branch reach T2.05 comprises 1884 feet (0.36 mi.) of stream that includes the remains of the old impoundment upstream of the Johnson Mill dam. Although the Vermont Dam inventory indicates that this dam was completed in 1928, indications are that a mill was operating on the site as much as 150 years ago, in the mid-nineteenth century (pers. comm., Mickey Lopes, garlic farmer in next reach downstream). The dam at the reach break on the downstream end of the segment is still mostly intact, though it is breached slightly on one corner and functions as a run of river impoundment at this point (Fig. 59).

Figure 59. The old Johnson Mill dam at reach break T2.05 is relatively intact, but the old mill buildings have burned leaving only the foundations.

A large impoundment shows up above the dam on 1924 topographic maps (http://docs.unh.edu/VT/enos24se.jpg), and is still relatively large in 1995 orthophotos taken during leaf-off conditions. During 2008 assessments, the stream was flowing in a mostly single-thread channel (with some braiding in localized areas) in the interior of the old impoundment, surrounded by an extensive herbaceous wetland (Fig. 60). The old pond appears to function as an oxbow wetland in wet conditions at least, and may remain wet even during the summer (Fig. 61). This area provides some value as an attenuation asset for high flows and sediment, but likely is a break in coarse sediment transport to downstream reaches that may have contributed to "sediment starving" and bed downcutting. While removal might aid channel evolution in downstream reaches, it would be costly and would need more in-depth assessment of the impacts of sediment discharges and possible headcutting upstream (the next grade controls are nearly a mile upstream, though bedrock 0.75 mi upstream is likely close to grade). The dam is located on bedrock, so removal may or may not have aquatic organism passage benefits.

Figure 60. The old mill pond above the Johnson mill dam in Bogue Branch reach T2.05 is now reduced to a mostly single-thread channel, with portions of the old pond (covered in snow here) functioning as an oxbow wetland (2009 aerial photo).

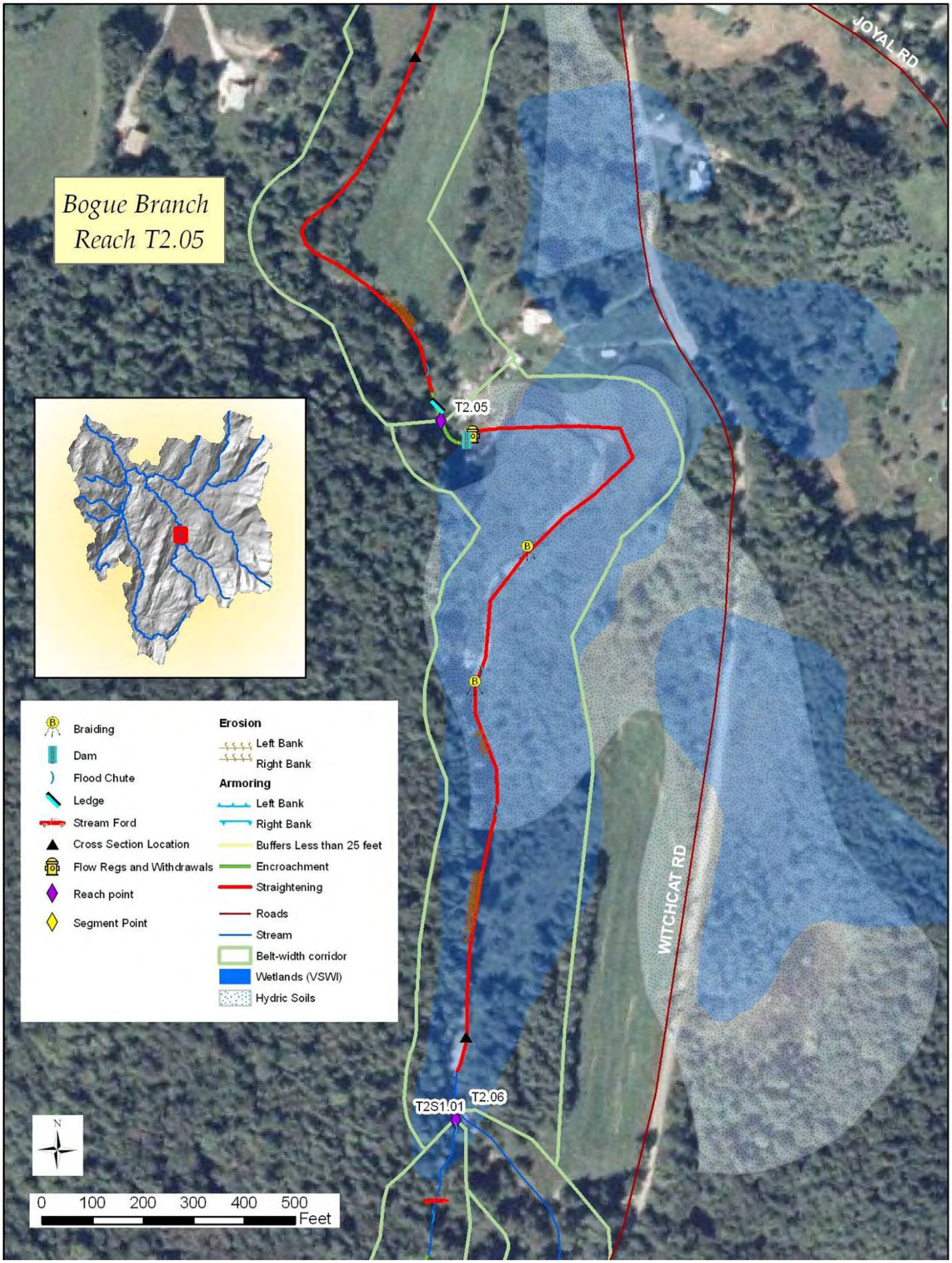


Figure 61. Reach map for Bogue Branch reach T2.05.

Distinguishing characteristics for reach T2.05 included:

- Old mill pond now has single channel and oxbow wetland that fills in wet periods
- Stream in wetland area is more E-type stream rather than the C-type of the upstream portion of the reach but was not segmented out due to its limited linear extent
- Minimal development encroachments, in the area of the dam
- Erosion on 10% of the right bank of the reach, in upstream area
- Intact buffers >100 feet, composed of herbaceous wetland plants and mixed trees
- Historical straightening evident in angle of approach to dam, now starting to change planform
- Gravel substrate, channel evolution stage III (widening and planform change), geomorphic condition Fair, stream sensitivity Very High

Table 19. Bogue Branch Reach T2.05 Projects and Practices Table.

River Segment	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
T2.05	Protect river corridor	Low	Moderate	Y	Attenuation asset for flow and sediment discharges, encroachment unlikely due to extensive wetlands; maintenance of existing buffers will aid during channel evolution and help mitigate flows

6.1.12 Preliminary project identification: Reach T2S1.01 - Bogue Branch, from confluence with Cook's Brook (near upstream end of second hayfield on Witchcat Rd. south of Joyal Rd. intersection) to confluence with unnamed tributary from Butternut Ridge (near downstream end of third hayfield on Witchcat Rd. south of Joyal Rd. intersection)

Bogue Branch reach T2S1.01 is 1395 feet in length (0.26 mi.) and was classed in Phase 1 as a C-type riffle-pool stream with a gravel substrate, situated in a Very Broad valley. The reach was not segmented for Phase 2 assessment and retained the stream typing from Phase 1. The valley and side slopes are largely forested (Fig. 62) and there has been significant logging activity in the last 5 years or so, extending up the valley from this reach through reach T2S1.03.

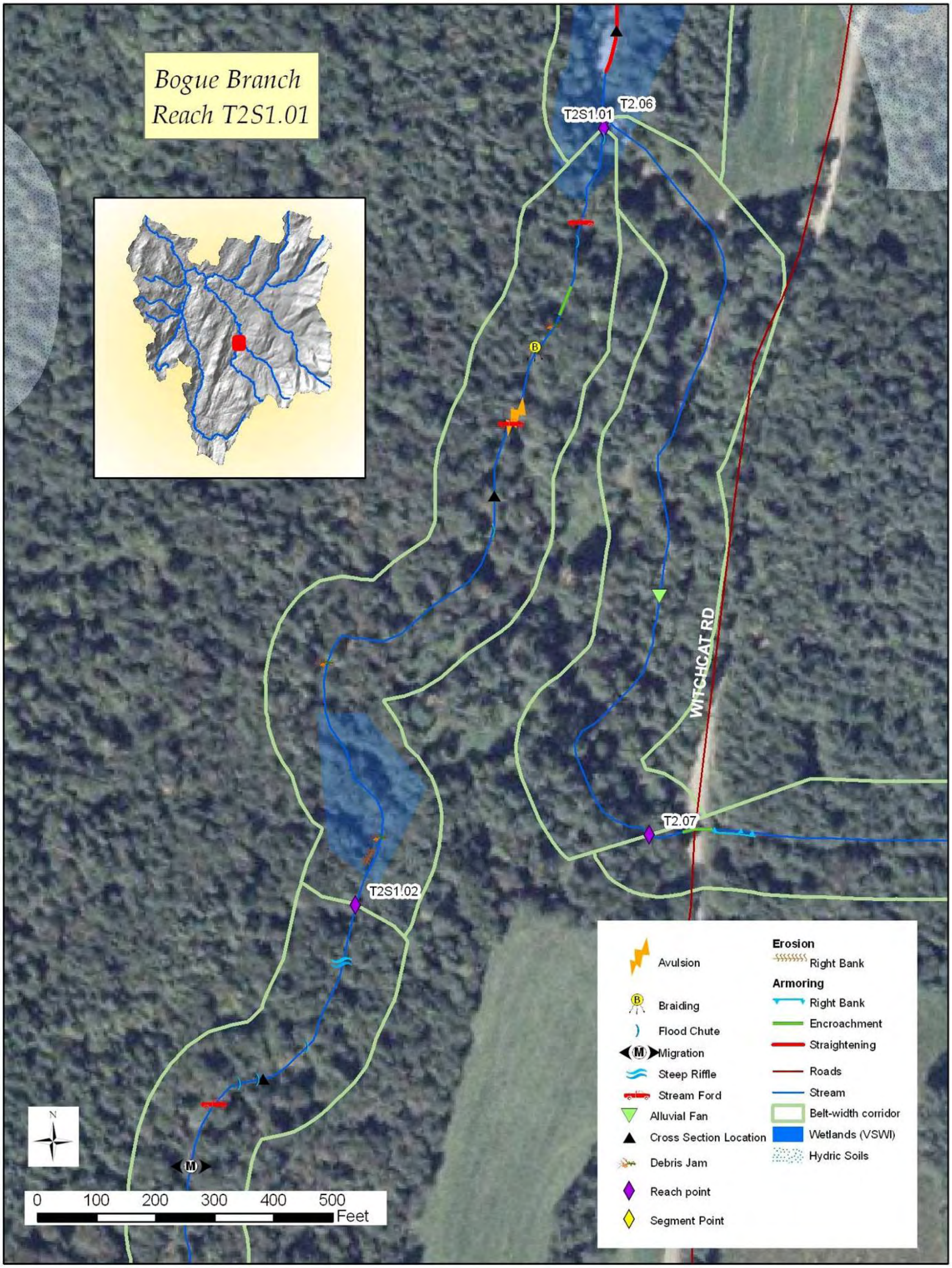


Figure 62. Bogue Branch reach T2S1.01 reach map.

An incision ratio of 1.8 in reach T2S1.01 indicates some loss of floodplain functionality in this area, but not complete loss of access at flood flows. Bedrock outcrops on the left bank at the upstream end of the reach close the valley wall tight on that side but do not form constrictions, and ledge outcrops in the streambed in this area are not channel spanning but are significant. These would be likely to limit further bed downcutting in this area (upstream migration of headcuts may be conceivable if the dam downstream in reach T2.05 is ever removed or largely breached).

Recent logging (within last 5 yrs) used a mid-reach flood chute for a skid road, and logging slash and discards appear to have contributed to a channel avulsion that has eliminated former meanders within the reach; the skid road/flood chute further reduces sinuosity and pushes the stream against the left valley wall. The channel avulsion occurred when a debris jam (at least some of which appeared to be logging slash and sawn LWD) plugged the former channel on the right bank, diverting the stream down the flood chute/skid rd several hundred feet.

Additional large woody debris at the downstream end of this flood chute was catching significant amounts of sediment, contributing to aggradation and channel braiding there. While the avulsion has temporarily eliminated meanders, the woody debris was playing a similar role to observations elsewhere in the watershed, where downed trees contribute significantly to sediment retention and development of new meanders.

Large woody debris also crosses the channel at three different locations spread throughout the reach, forming check dams and retaining sediment; it was unclear whether these were purposely placed to limit bed degradation.

Features of note for reach T2S1.01 included:

- One small cabin, unoccupied, and no other development or encroachments
- Bedrock-controlled lower banks, but upper banks are sandy
- Forested buffers >100 feet both sides
- One stream ford, which appears to get some ATV use
- Channel evolution stage III, planform change partly related to skidding, partly due to large woody debris sediment storage and meander formation; geomorphic condition Fair, stream sensitivity Very High

Table 20. Bogue Branch Reach T2S1.01 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T2S1.01	Protect river corridor	Moderate	Low	Y	Attenuation asset

6.1.13 Preliminary project identification: Reach T2S1.02 - Bogue Branch, from approximately 1600 feet upstream of the confluence with Cook's Brook to approximately 2500 ft downstream of Page Road bridge.

Bogue Branch reach T2S1.02 is 2,263 ft long (0.43 miles) and was segmented once during the Phase 2 process. Segments are 1,079 and 1,185 feet in length. The reach is situated in a Narrow valley, and Phase 1 characterized it as a C stream with a riffle pool bedform. T2S1.02A holds true to a C-type stream with a riffle pool bed, but is found in a Broad valley. The valley narrows for Segment B to the extent that this segment is classified as a B-type stream with a c-subslope (<2%). Both segments have gravel beds.

Segment A (1,079 ft) comprises approximately half the reach and has a Broad valley with bedrock ledge along the left valley wall. Key features include:

- Dominant buffer on both banks is >100 ft.
- There is a small clearing and cabin along the right bank in mid-segment.
- There is no encroachment on this segment.
- There is a moderate amount of aggradation; with 1 mid-channel bar, 11 side bars, 2 diagonal bars, and 3 steep riffles being mapped.
- Flood chutes are fairly common and appear to be historic channels indicating past stream avulsions. Four flood chutes were mapped.
- There are two fords in this segment.
- The stream is in stage IV. There is some incision and widening appears to be a moderately active process in some parts of the segment. Overall, aggradation is dominant, however. New flood plain benches are being built and the stream appears to be stabilizing.
- Substrate is gravel, sensitivity rating is Very High, and geomorphic rating is Fair.

Figure 63. Bogue Branch reach T2S1.02 segment A: bank erosion where widening is occurring is also causing trees to fall into stream.

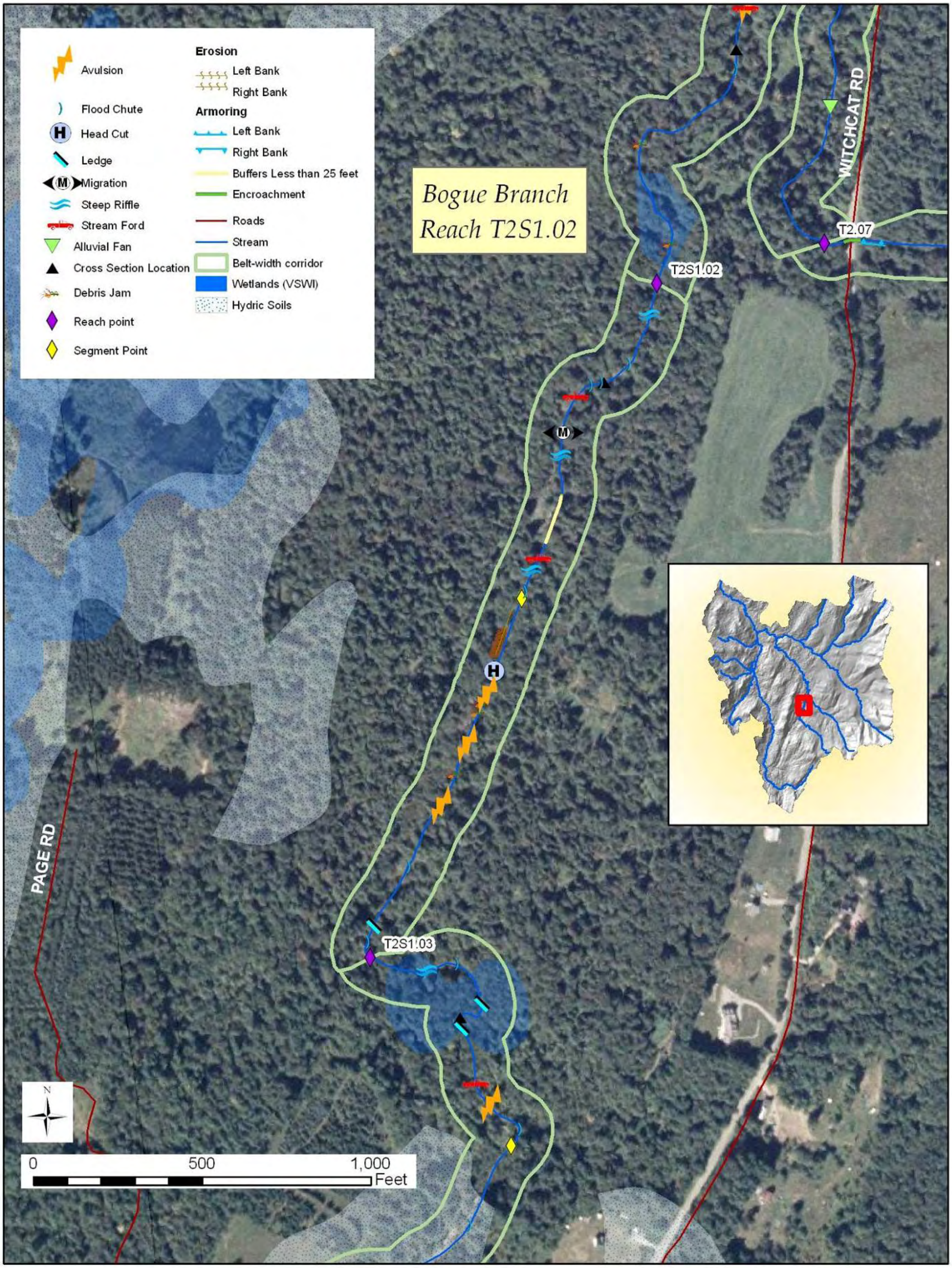


Figure 64: Bogue Branch reach T2S1.02.

Segment T2S1.02B (1,185 ft) comprises the upper half of the reach and also has a forested buffer. Bedrock along the left valley wall pinches in for this segment, creating a narrow valley setting. Past timber harvesting appears to have impacted this stream section, and it is surmised that the skidroad followed the stream channel. This has affected the bedform, which now fits a planebed classification, and has impacted the stream to the extent that it is difficult to tell if the segment may be an alluvial fan; it was almost considered a B to D stream type departure. Soil maps show only a small amount of hydric soil in the valley. Key features for this segment include:

- Buffers on both sides are >100 ft.
- There is no development or encroachment on this segment.
- It appears that this stream channel has been used for skidding in the past. Although straightening was not mapped, the effect of skidding was to straighten and widen this stream channel.
- There is one ledge grade controls at the top of this segment. It measures 2 feet in height.
- Lateral movement seems to be common for this section of stream and there were 3 flood chutes and 3 recent channel avulsions mapped.
- The stream is in stage III, with major aggradation and planform changes occurring. Past skidding in the channel has caused widening.
- Substrate is gravel, sensitivity rating is Very High, and geomorphic rating is Fair.

Figure 65: Bogue Branch reach T2S1.02 segment B. Past skidding has significantly widened the stream channel (left) and channel avulsions are common in this segment (right).

Table 21. Bogue Branch Reach T2S1.02 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T2S1.02 A T2S1.02 B	Protect river corridor	Moderate High	Moderate Moderate	N	Some attenuation assets present here. A considerable amount of channel instability indicates the entire stream valley is important for stream function, accommodation of aggradation and lateral migration.

6.1.14 Preliminary project identification: Reach T2S1.03 – Bogue Branch, from approximately 2500 feet downstream of Page Road bridge to 180 feet upstream of same bridge.

Reach T2S1.03 is 2,100 ft long (0.40 mi.) and was segmented twice during the Phase 2 process. Segments are 978 , 772 and 988 feet in length. The reach is quite variable, but was classed overall as a reference C-type stream with a 'b' subslope (2-4%) in a Narrow valley.

- T2S1.03A is a subreach typed in Phase 2 as an overall B-type stream in a Narrowly Confined valley, but has smaller C- and A-type inclusions and a roughly 3.4% slope
- T2S1.03B is a borderline C/B type (typed C in Phase 2) with a riffle-pool bedform, located in a semi-confined valley, with roughly 1.8 % slope
- T2S1.03C, is a C-type riffle pool stream with a cobble substrate, ~1.5% slope

Soil maps show that both hydric soils and Vermont Significant Wetland Inventory mapped wetlands are a significant presence in this valley (Fig. 66).

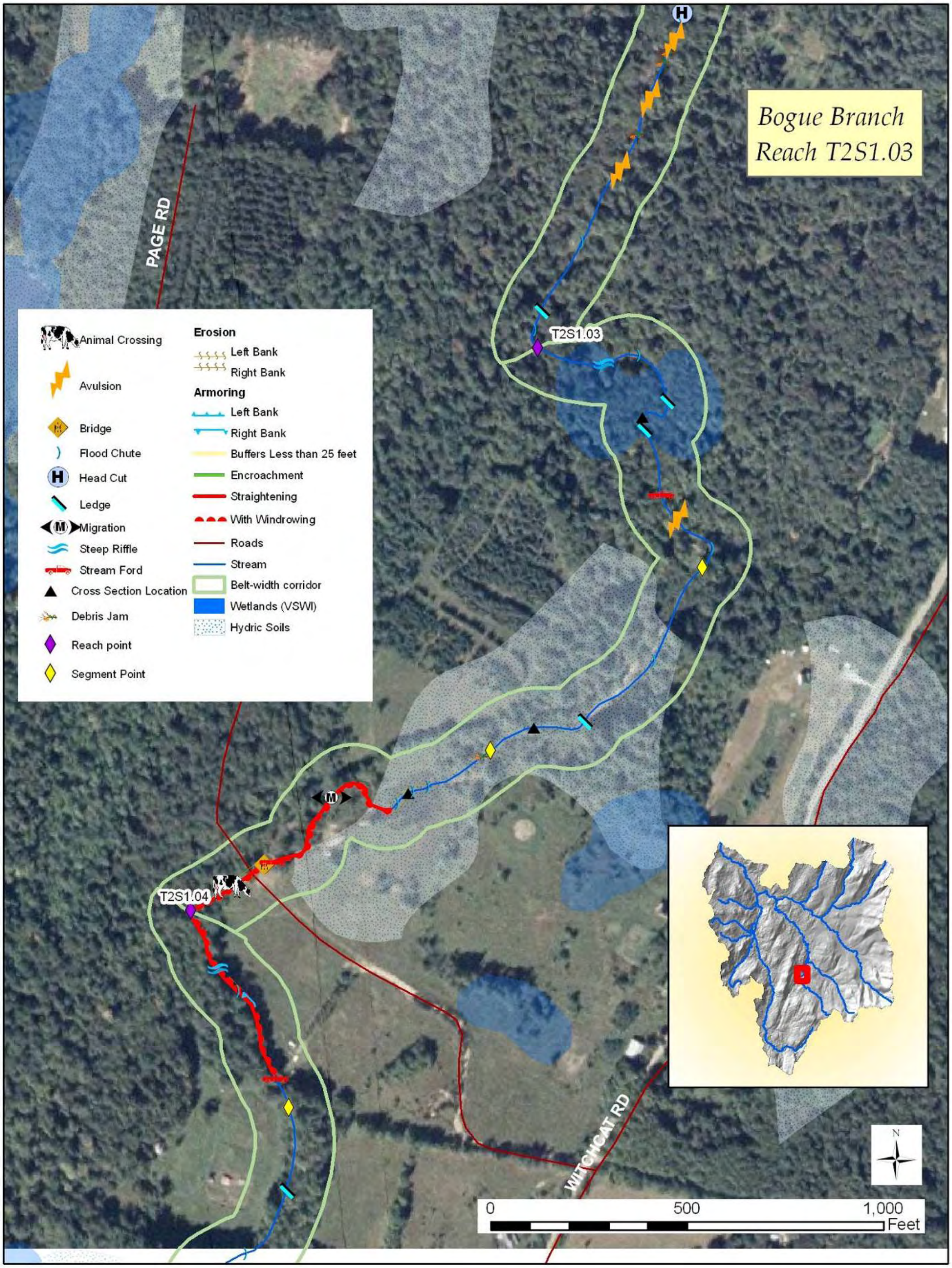


Figure 66: Reach map for Bogue Branch reach T2S1.03.

T2S1.03A (978 ft) is a subreach. This segment is characterized by a narrowly confined valley with a B-type stream and a step-pool bedform. This segment is quite variable, with narrow and steeper bedrock-controlled sections alternating with areas with a wider valley and lesser slopes. Key features include:

- Dominant buffer on both banks is >100 ft.
- There is no encroachment or development on this segment.
- Lateral movement is somewhat common and 3 flood chutes and one channel avulsion were mapped for the segment.
- Two ledge grade controls are found in mid-segment with one having a total height of 7 feet. There is a constriction also associated with this grade control.
- The stream is in stage I; bedrock serves to stabilize this segment.
- Substrate is gravel, sensitivity rating is Moderate, and geomorphic rating is Reference.

Figure 67: Bogue Branch reach T2S1.03 segment A is stabilized by bedrock features.

T2S1.03B (772 ft) is characterized by a semi-confined valley with alder wetland characteristics. There were very few features mapped in this segment. There is evidence of old beaver dams upstream. Key features for this segment include:

- Buffers on both sides are >100 ft.
- There is no development or encroachment on this segment.
- There is one small ledge grade control in mid-segment.
- Lateral movement seems to be common for this section of stream and there were 3 flood chutes and 3 recent channel avulsions mapped.
- The stream is in stage I; intact wetland buffer may help stabilize this section of stream, as it appears stable. Some sediment movement through the segment.
- Substrate is gravel, sensitivity rating is Moderate, and geomorphic rating is Good.

T2S1.03C (988 ft) appears to have been highly impacted by past beaver and human activity. There is evidence of old beaver dam material toward the bottom of the segment and evidence of channelization and straightening up and downstream of the Page Road bridge. Channel features have been altered to the extent that the bed form is planebed, and it is possible that the channel was bulldozed after 1997 or 1998 flooding; the bridge appears to have been replaced somewhere in that time period. Key features for this segment include:

- Buffers on both sides are >100 feet, but buffer vegetation is made up of grasses and herbs and does not provide cover for the stream.
- There is no encroachment, and very little development, on this segment.
- Almost 70% of the segment shows signs of straightening with windrowing.
- There is a bridge channel constriction in mid-segment with some deposition occurring upstream.
- Judging from historic topos, the stream channel location has changed significantly in this segment; probably due to past beaver activity, breaching of the beaver dam, and consequent human intervention.
- The stream is in stage IV. Historic disturbance has led to the forming of new flood plain terraces and the stream appears to be stabilizing
- Substrate is gravel, sensitivity rating is High, and geomorphic rating is Fair.

Figure 68: Bogue Branch reach T2S1.03 segment C shows signs of channel straightening and windrowing following beaver damming.

Table 22. Bogue Branch Reach T2S1.03 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T2S1.03 A T2S1.03 B T2S1.03 C	Protect river corridor	Moderate High High	Moderate High High	N	Considerable attenuation assets present here.
T2S1.03 C	Re-establish buffers	High	High	Y	Buffer here has been impacted by past beaver and human activity. Allow it to re-establish or plant.
T2S1.03 C	Replace Existing Bridge Structures	Moderate	Moderate	Y	When bridge is due to be replaced, replace it with a structure that does not constrict stream channel.

6.1.15. Preliminary project identification: Reach T2S1.04 – Ross Brook from confluence with Bogue Branch upstream of Page Rd. bridge to the headwaters

Reach T2S1.04 includes the entirety of Ross Brook from its confluence with Bogue Branch to the headwaters in a saddle between Peaked Mountain and the Cold Hollow Mountains, covering roughly 15,000 feet (2.84 mi.). The reach was classed as a B-type step-pool stream as reference, with an 'a' subslope (4-10%) and a cobble substrate. Phase 2 assessments broke the reach into four segments, including two subreaches (segments A and C):

- T2S1.04 A , ~ 581 ft = C riffle pool, ~1.9% slope, cobble substrate
- T2S1.04 B, ~2463 ft = B step-pool, ~6% slope, cobble substrate (Fig. 69)
- T2S1.04 C, ~6,972 ft = C riffle-pool, ~ 3.5% slope, gravel substrate (Fig. 70)
- T2S1.04 D, ~4968 ft = alternating short sections of B- and C-type channels with intermittent cascades and waterfalls interspersed throughout as well; ~ 7.5% slope overall, typed as B, subslope 'a' (4 -10%) in Phase 2 (Fig. 73)

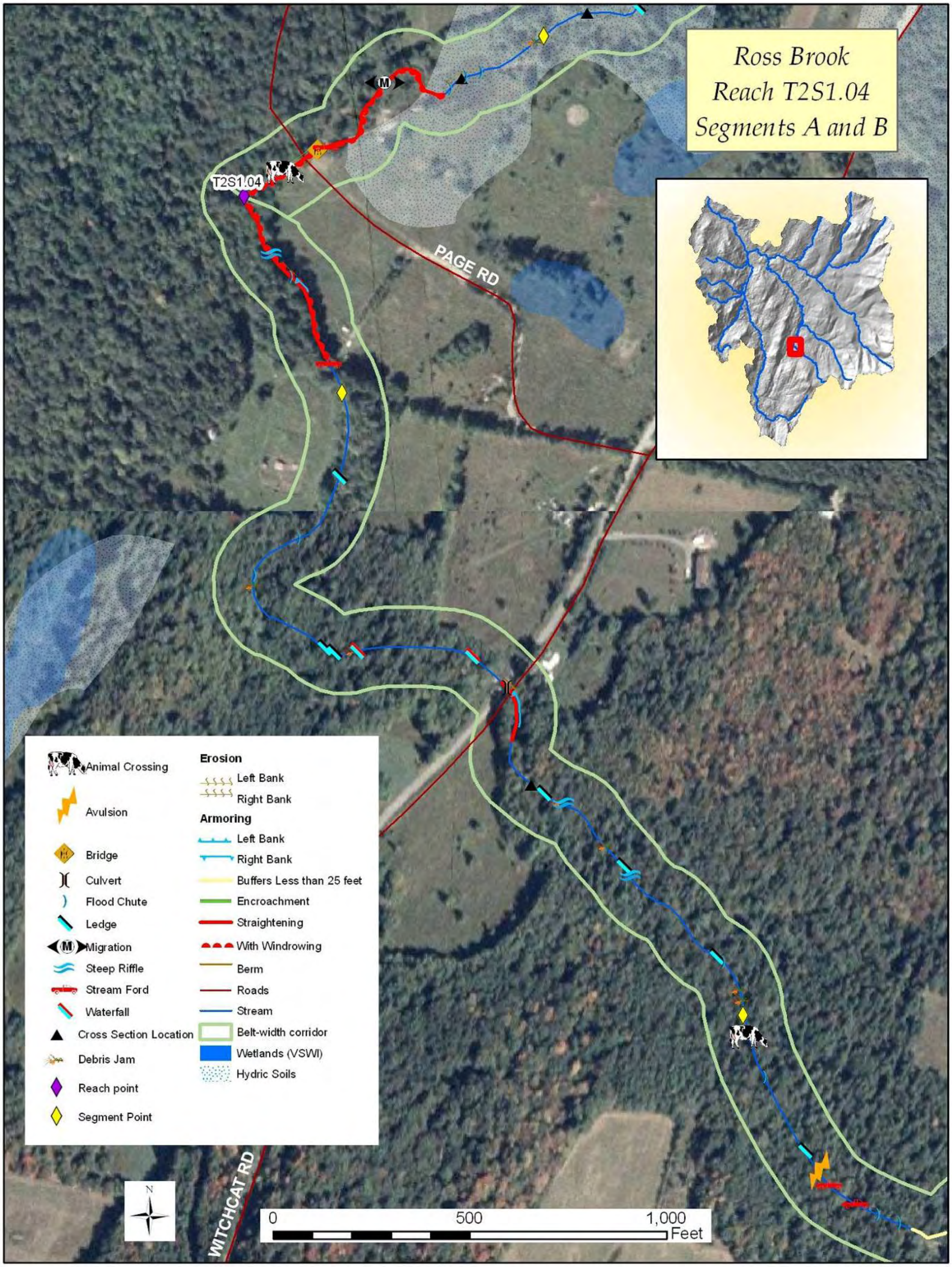


Figure 69. Map for Ross Brook segments T2S1.04A and T2S1.04B.

Segment T2S1.04A is a very short segment (581 feet) of the reach that effectively functions with T2S1.03C, the next downstream segment, in terms of stream dynamics. The right bank corridor is in moderate intensity agricultural uses, including hay, a large garden and pasture, while the left corridor is forested. It appears that the Page Rd. bridge just downstream of this segment, in segment T2S1.03C, was replaced (probably after 1997 or 1998 flooding) and the stream may have been "cleaned out" upstream and downstream of that bridge at that time. Bulldozing may have extended through much of this segment as well (based on observation, not confirmed), with windrowing that is not high enough to form a berm but did widen the stream channel. Enlarged point bars were evident and a gravel ramp had built into the field, indicating the value of this segment for sediment attenuation.

- Distinguishing features for T2S1.04A included:
- No development or encroachment in the corridor
- Buffers >100 feet on the left bank, but just barely >25 feet on the right bank
- Channel evolution stage III, widening and planform change following likely post-flood dozing of channel; evolution may be slowed by windrowing
- Cobble substrate, geomorphic condition Fair, stream sensitivity High

Segment T2S1.04B (2463 feet) is dominated by bedrock grade controls with frequent cascades and waterfalls. Intermittent B-type step-pool areas exist throughout, and the stream and valley widen in these step areas. Key features included:

- No development; minimal encroachments include a short stretch of berm and riprap at the Witchcat Rd. culvert above a set of waterfalls
- The squashed culvert at Witchcat Rd. above the waterfalls is sized at 43% of reference bankfull channel width and presents both a channel and floodprone constriction, but minor scour of the footers below the culvert was the only indicator of potential problems.
- Dominant buffers >100 feet, with short stretches of buffer 26-50 feet near the Witchcat Rd. Rd. bridge
- Channel evolution stage IV, largely stabilized after historic incision; geomorphic condition Good, stream sensitivity Moderate; natural Transport reach

Segment T2S1.04C extends roughly 6972 feet, from about 1150 feet upstream of the Witchcat Rd culvert to the beginning of ledge grade controls upstream of the Branon sugarhouse at the end of Peaked Hill Rd. (Fig. 70). This segment represents valuable attenuation assets high in the watershed that have been impacted significantly by a combination of cattle, human, and weather-related causes that will be important to address for downstream projects to have an increased chance of success.

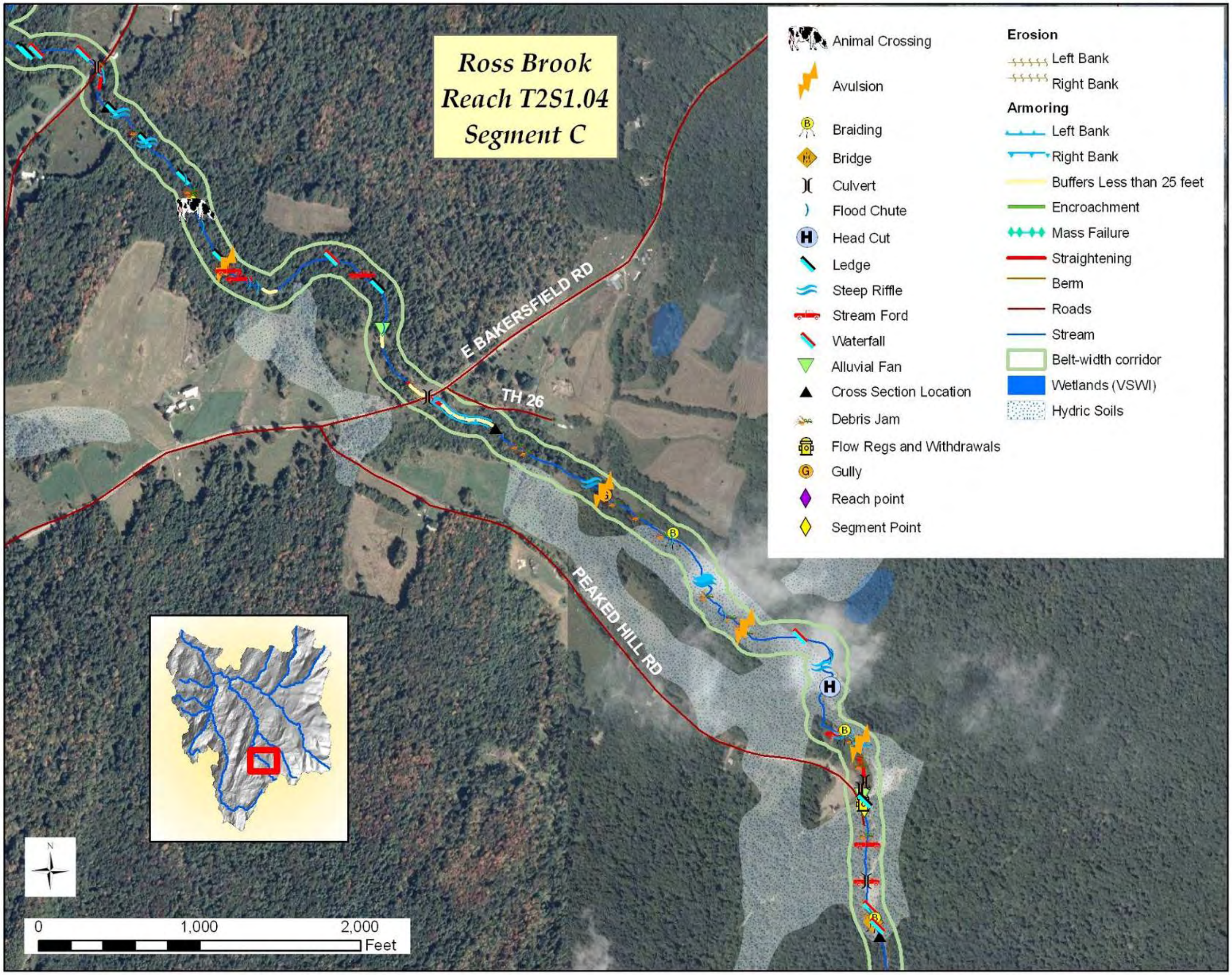


Figure 70. Map for Ross Brook segment T2S1.04C.

Segment T2S1.04C passes through a recently logged corridor that has a good bit of streamside cutting and several logging crossing points, some of which are used for cattle access to the woods across the stream. More open pasture is visible downstream of a squashed culvert at East Bakersfield Rd., and cattle have unrestricted access to most of the stream from this area extending to the upper portions of the segment. Rotational grazing paddocks appear to be fenced across the stream above East Bakersfield Rd. and extend west to the border of Peaked Hill Rd., and there are some steep erodible sideslopes in this area that have slid under impacts from grazing cattle (Fig. 71). The pasture along Peaked Hill Rd. includes a lot of alder wetland that has been heavily impacted by grazing, and a 200 foot long, 5-6 foot deep gully opened beneath a drainage coming down to segment T2S1.04C from the pasture during summer 2008 storms; this was not necessarily caused by the grazing.

Figure 71. Rotational grazing paddocks appear to be fenced across the stream in segment T2S1.04C, and steep erodible sideslopes have slid under impacts of grazing cattle in some areas.

In the upstream portions of segment T2S1.04C, the Branon sugarhouse appears to be located on what may be an alluvial fan, underlain by hydric soils. Several culverts have been installed to channelize streams under the road system that was built to access the property, all of which are undersized to some degree and present both channel and floodprone constrictions. The main culvert that carries Ross Brook is a 7 foot smooth steel culvert that is sized at about 70% of the reference channel width for the stream at this point. Sediment deposition was evident upstream of all of these culverts, likely due to discharges in flash flooding that hit the area upstream of here hard during the summer of 2008. A beaver dam shortly downstream of the culverts was blown out during the storm that caused the flooding, and a significant headcut with potential for upstream migration was evident upstream of the former beaver pond (Fig. 72).

Figure 72. Headcut upstream of beaver pond blow-out in Ross Brook segment T2S1.04C from summer 2008.

The combination of recent flood impacts and changes in the Branon sugarbush further upstream (T2S1.04D), including road layouts with additional direct stormwater inputs and areas where the stream has captured portions of a road as an extension of the channel, add up to significant changes in the hydrology in this area. Given these impacts, segment T2S1.04C has particularly valuable assets for attenuating flow and sediment loads before they exacerbate other adjustment processes further downstream. While buffers in the segment are not completely diminished, augmentation of existing buffers and retention of trees in the riparian corridor can greatly aid stream dynamics in this type of stream over the long run (the contributions of trees are further discussed in Sec 5.1.1, Watershed-scale hydrologic stressors, of this report). Key features of segment T2S1.04C included:

- C-type riffle-pool stream substrate may be cobble under reference conditions, but was measured as gravel at the cross-section; may indicate aggradation from upstream sediment discharges
- Incision ratio of 1.5 indicating some impairment of floodplain access
- Small amount of development and encroachment concentrated around the East Bakersfield Rd. bridge and the Branon sugarhouse at the end of Peaked Hiil Rd.
- Two mass failures and one gully
- Small amounts of erosion and revetments accounting for <5% of the reach on each bank
- Diminished buffers but only 400-450 feet of each bank lacking buffers
- Significant aggradation in multiple bar types
- 15% of the segment is straightened
- Four stormwater inputs and five stream fords
- Three culverts and one bedrock constriction all had sediment deposits upstream
- Three areas of ledge grade controls and two waterfalls
- Channel evolution stage III, primarily planform change and aggradation
- Gravel substrate, geomorphic condition Poor, stream sensitivity Very High

Segment T2S1.04D comprises the 4968 feet of Ross Brook from the beginning of bedrock grade controls just upstream of the Branon sugarhouse at the end of Peaked Hill Rd. to the headwaters of the stream. This area is part of a 16,000 tap sugarbush, and the road network crosses through much of the subwatershed for this stream and two others draining these uplands. One of the sugarbush roads appears to have been mapped as the stream at some point, as the Vermont Hydrography Dataset used for Phase 1 and 2 assessments coincides directly with the road, whereas 1986 topographic maps show the stream channel further to the east, which gibes with GPS tracks collected during 2008 Phase 2 assessments (Fig. 73). This discrepancy has been reported to the VT stewards of this dataset (VCGI). Features mapped with the tools used for Phase 1 and 2 assessments are automatically placed on the VHD streamline, and mapped locations are thus set further west than their actual locations in the field (Fig. 74).

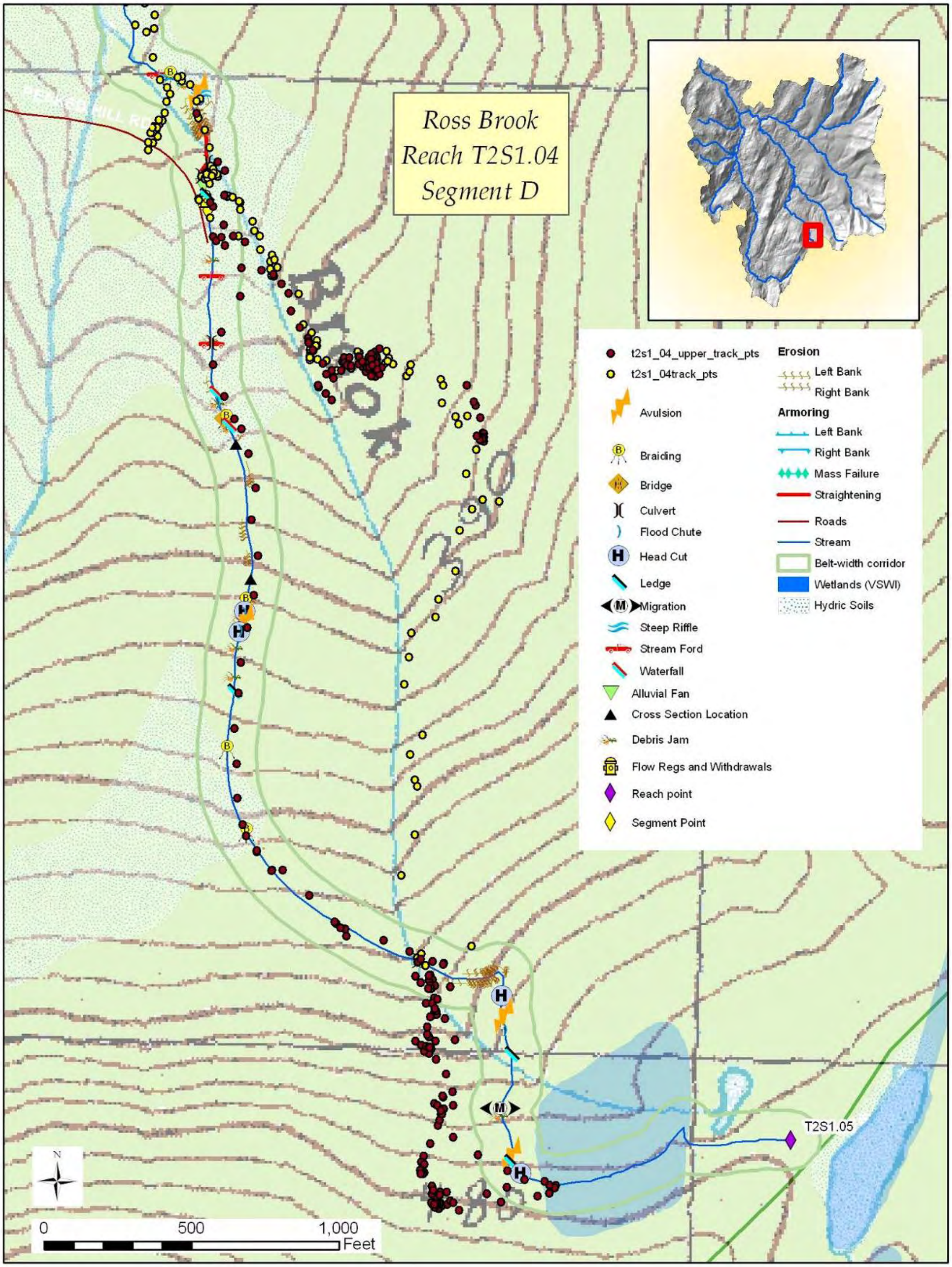


Figure 73. GPS tracks taken along Ross Brook segment T2S1.04 on two different days (yellow and red) indicate that the current stream location coincides better with the streamline indicated on 1986 USGS topographic maps than that indicated by the Vermont Hydrography Dataset (VHD) streamline on which stream impacts and features are mapped. The relatively evenly spaced red points along the VHD at left were collected while walking the main road in the Branon sugarbush.

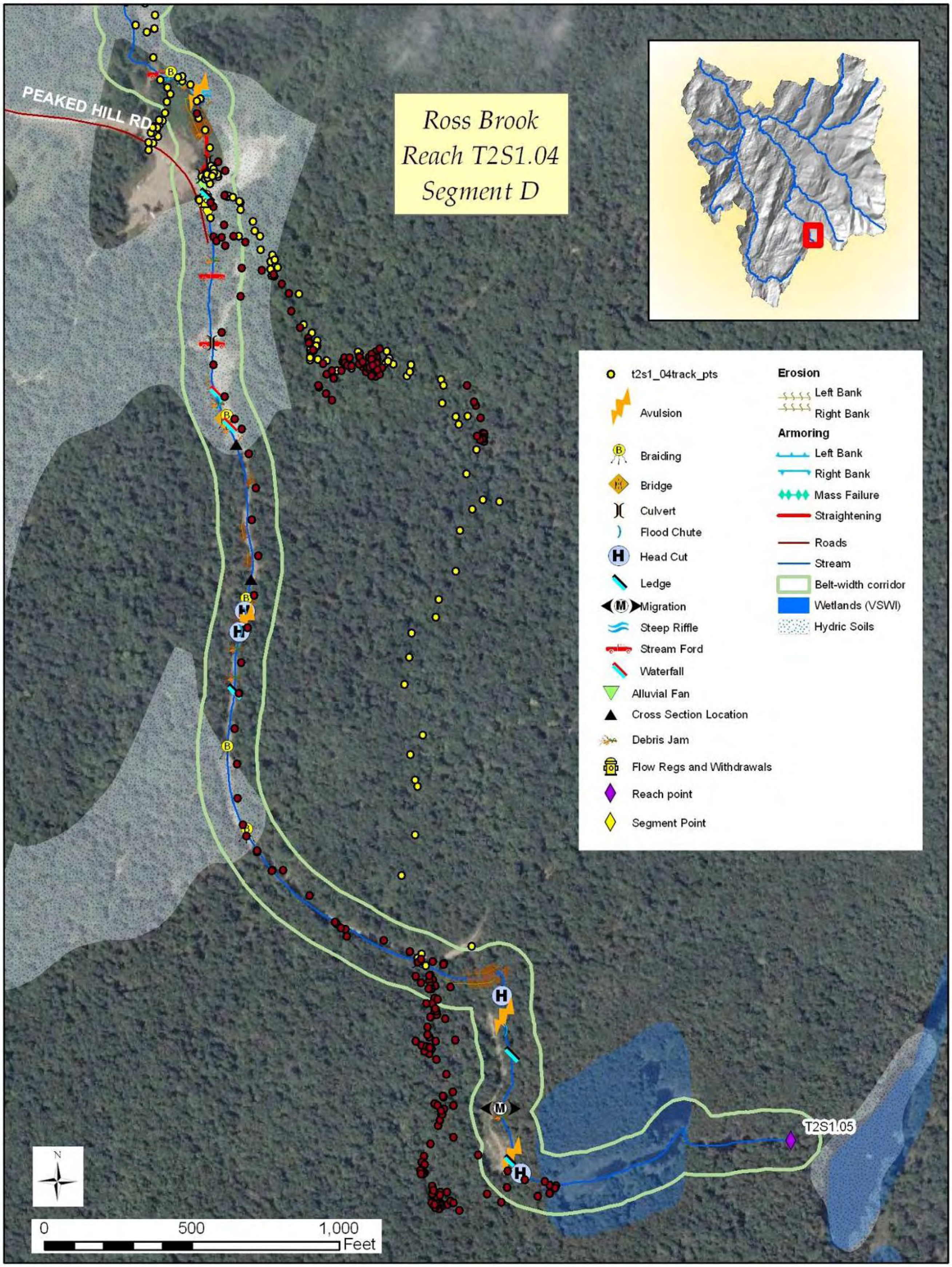


Figure 74. Map for Ross Brook segment T2S1.04D. Yellow GPS track points and clustered red points indicate current stream location.

Further discrepancies on the mapping of segment T2S1.04D occur on the 1986 USGS topos as well. The mid-segment "bulge" in the stream line (Fig. 74) indicates a recent channel avulsion (Fig. 75) that created a new meander in the stream with access to valuable assets for attenuating flow and sediment loads. Beaver ponds at the top of the reach do not drain to this segment as indicated on the USGS topo maps and VHD streamline, rather draining north (larger ponds just to the east drain NNE into another watershed); the closest pond to the head of the reach probably drains back to this segment further downslope in an intermittent tributary that was captured by the recent channel avulsion.

Figure 75. Recent channel avulsion in segment T2S1.04D helped create a new meander that offers opportunities for attenuation of flow and sediment loads. 18 in. culvert visible in background was one of three along this segment that got plugged and outflanked in recent flash flooding.

Segment T2S1.04D is very shallow to bedrock through most of the segment and alternates between short sections of B- and C-type channels, with intermittent waterfalls and cascades interspersed throughout as well. Although slope is around 8% for the overall segment, the majority of this occurs in the waterfall and cascade sections and the slope is less steep and the valley less confined in other areas, especially the area of the new meander.

Recent flash flooding carved multiple flood chutes and braids in the shallowest soils, outflanked most of the 18 in. culverts along Ross Brook in the sugarbush, initiated several headcuts near or on sugar roads (Fig. 76; further upstream migration of these is distinctly possible), and caused several avulsions that followed those roads. It is difficult to assess the extent to which the stream capture of these roads is extending the stream network without mapping the roads rather than the stream channel. Some further incision is possible, particularly in pockets of C stream with available floodplain in the area of recent stream migration in the middle of the segment, and the stream was assessed using an F model for channel evolution primarily because of this.

Figure 76. This headcut is moving up a road in the Branon sugarbush on segment T2S1.04D. Several headcuts like these are impacting the roads as well as posing the potential for extending the stream network, increasing flows in the stream while eliminating access to valuable floodplains.

Key features for segment T2S1.04D included:

- No development, but road encroachment (private sugarbush roads) is present but difficult to assess due to recent stream migrations and capture of roads in some areas. The roads had been laid out to cross the stream and were generally not running within the corridor previously.
- Four road ditch stormwater inputs (from private sugarbush roads)
- Only one 18 in. culvert still functional, three others were blown out by flash flooding and are no longer functional
- Two waterfalls and three ledge grade control series
- Nine debris jams, four flood chutes, three channel avulsions, four areas of braiding
- Four headcuts: two undercutting roads transverse to stream (one on a trib off of the "main channel"), one moving up a road
- Shallow to bedrock: could have been assessed with a D model for channel evolution (stage IIc), but has access to floodplain and could incise more in some areas and was thus assessed using F model evolution
- Stage II-III channel evolution incision and planform change, incision related to recent flash flooding
- Gravel substrate dominant due to aggradation; geomorphic condition Fair, stream sensitivity High

Table 23. Bogue Branch Reach T2S1.04 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T2S1.04 A T2S1.04 B T2S1.04 C T2S1.04 D	Protect river corridor	Moderate Low High Moderate	Moderate Low High Moderate	N	Low level constraints in all segments. A and C particularly valuable as attenuation assets, flow attenuation important in D. Prioritize upstream impacts.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T2S1.04 A T2S1.04 C	Augment and establish buffers where lacking	Moderate Moderate	Moderate High	Y	Low-cost: lateral instability; in A may regenerate if not mowed
T2S1.04 D (4)	Arrest head cuts	High	Moderate	Y	Further assessment needed for threats to roads and how much floodplain might be lost; the two in mid-segment are higher priority than upstream
T2S1.04 B T2S1.04C	Replace structures	Moderate Town: Moderate	Low Town: Low	Y	All structures undersized with deposition above. Town: Witchcat Rd. (seg B) reduced by angle of alignment, but situated at bedrock; both this and E. Bakersfield Rd. (Seg C) culverts are bottomless arch and have small deposits upstream; low priority unless damaged and needing replacement

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T2S1.04C	Replace structures (cont'd)	Private: Moderate	Private: High		Seg C Private: Culverts at Branon sugarhouse are likely private and would be expensive to replace, but significant deposition upstream from recent flooding; bridge would be ideal for Ross Brook crossing; structures channelize streams at likely alluvial fan, contributing to increased flow impacts downstream
T2S1.04D		High	High		Three of four 18 in. culverts blown out by recent flooding, though appear sized in accordance with forestry stream crossing AMPs; assess how much these crossings are used, with what equipment, and best strategies for these crossings

6.1.16 Preliminary project identification: Reach T3.01- Beaver Meadow Brook (Enosburgh) from the confluence of the Tyler Branch mainstem to approximately 230 feet upstream of the Nichols Road bridge.

Reach T3.01 is 4,350 feet long (0.82 miles) and was segmented twice during the Phase 2 assessment process. Segments are 1,940, 1,160 and 1,251 feet long. Overall the valley is Very Broad but the lower portion is significantly more confined than the upper portion. Soil maps show that hydric soils dominate the upper part of the stream valley, and this part of the reach appears to be important as an attenuation asset. The Phase 1 process classified this reach as a C-type stream with a riffle-pool bedform and gravel substrate. None of the segments retained this classification during the Phase 2 process. Segment A was determined to be an F stream by reference. Segments B and C have both experienced stream type departures due to incision and encroachment.

T3.01A is 1,940 feet long and is characterized by frequent ledge grade controls and a narrowly confined valley. This segment was re-classified as a reference F-type stream during the Phase 2 process. Key features include:

- There were 3 measured grade controls in the segment, one of which measured 27 feet in height.
- There are two mass failures in this segment.
- There is >20% road encroachment along one side of this segment.
- There is one bridge showing signs of deposition both above and below.
- There is a small amount of straightening and armoring associated with the bridge and house encroachment.
- The stream is in stage IIc (using D evolution model). Bedrock controls incision and widening occurs where bedrock allows.
- Substrate is cobble, sensitivity rating is High, and geomorphic rating is Good.

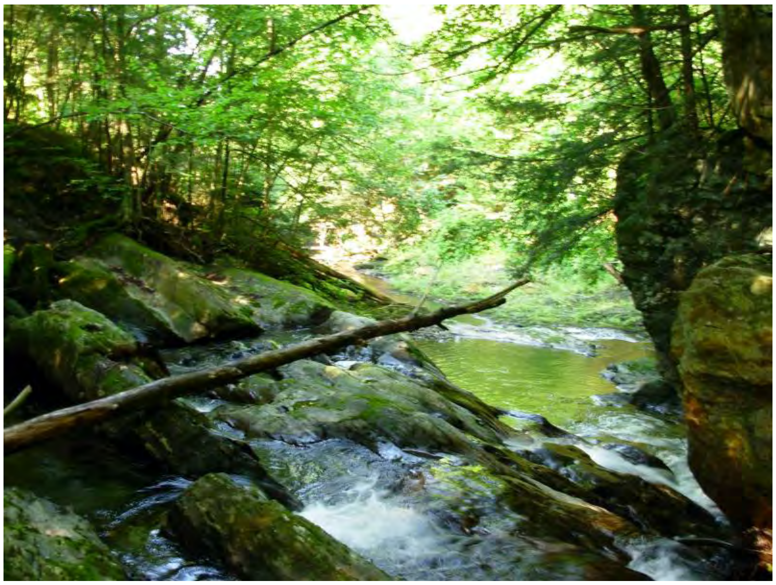


Figure 77: Beaver Meadow Brook (East Enosburgh), Reach T3.01, segment A, bedrock cascade.

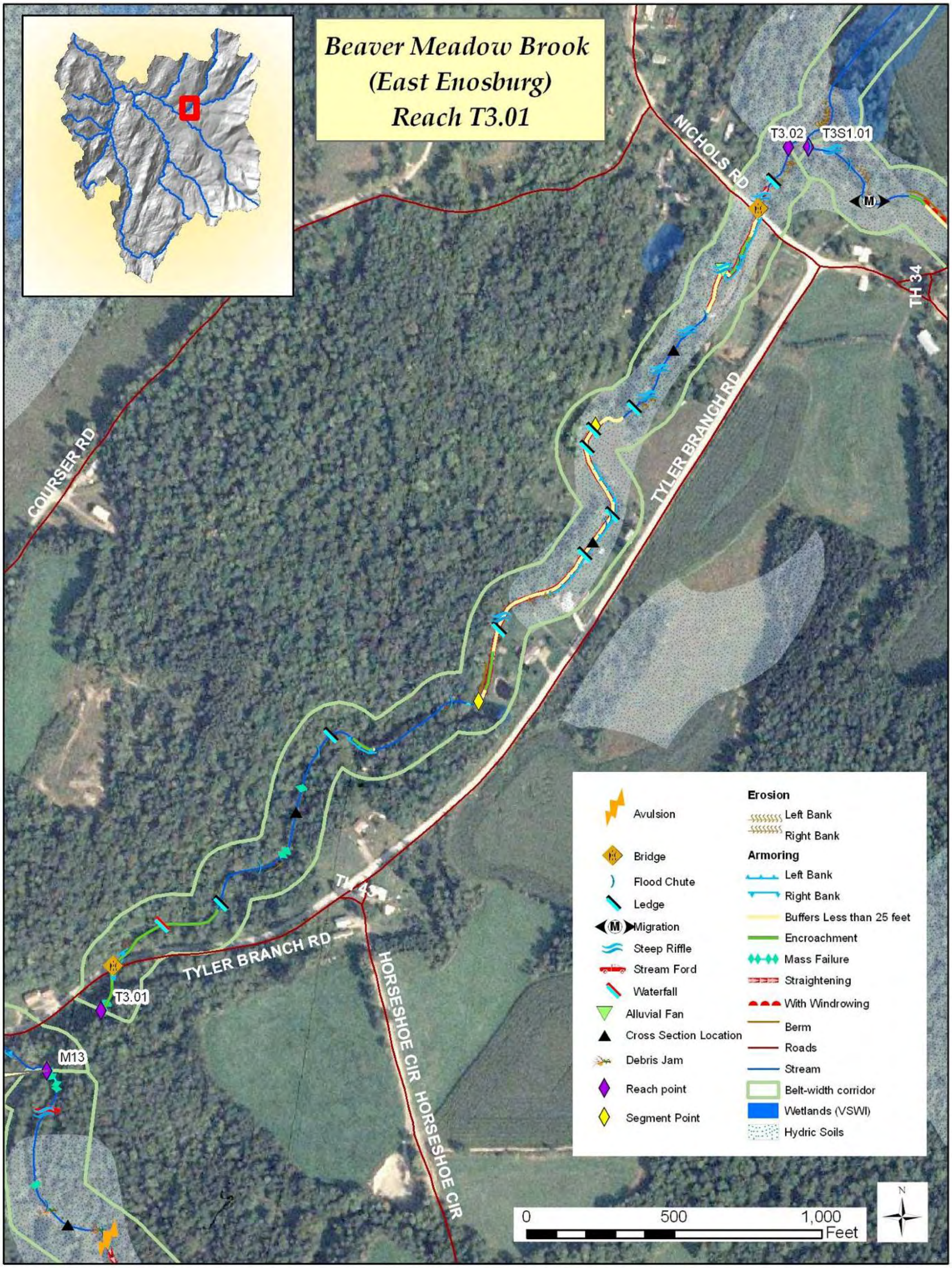


Figure 78: Beaver Meadow Brook (East Enosburgh), reach T3.01.

T3.01B is 1,160 feet long. It has a broader valley than segment A and a much gentler gradient. Encroachment along the left bank has significantly affected this section of stream. Incision has caused the stream to lose access to floodplain, in some areas narrowing the valley by as much as 600 feet. Key features include:

- There is more than 65% development along the left bank.
- Buffer along the left bank is <25 feet for the entire segment.
- Armoring is found along 40-50% of the left bank.
- Almost the entire segment has been straightened.
- A berm measuring 12 feet (height above thalweg) was measured for 105 feet along the left bank.
- Five grade controls were measured in this segment. All were 2 feet or less in height.
- There is a pond in the lower segment that stream bank erosion could destabilize.
- The stream is in stage II, with incision the most active process and widening arrested by combination of riprap and bedrock in stream banks.
- Substrate is boulder (due to high bedrock presence), sensitivity rating is High, and geomorphic rating is Fair.

Figure 79: Beaver Meadow Brook (East Enosburgh), reach T3.01 segment B has significant left bank encroachment (upper left), bedrock grade controls (upper right). Lower segment has pond embankment that is being eroded by stream channel (bottom).

T3.01C is 1,251 feet long. This section of stream is also characterized by having some bedrock in the bed and having a similar valley and slope to segment B. Left bank encroachment has also significantly affected this segment. This segment has incised sufficiently to have lost access to much of its original floodplain. The resulting encroachment has caused a stream type departure from C to B. Key features include:

- Buffer along more than 40% of the left bank is less than 25 feet.
- More than 50% of the segment has been straightened.
- Armoring approaches 20%, with some on both banks.
- There is a new development on the left bank near the bridge that appears to have manipulated the stream's planform somewhat (Fig. 80). New riprap is found in this location as well.
- Two grade controls were measured in this segment. Both were 3 feet or less in height.
- There is one bridge in the segment that shows signs of deposition both above and below.
- The stream is in stage IV, with historic incision followed by widening. Aggradation has formed new floodplain benches and the stream appears to be stabilizing in this segment.
- Substrate is gravel, sensitivity rating is Very High, and geomorphic rating is Fair.


Figure 80: Beaver Meadow (East Enosburgh), reach T3.01 segment C. Aggradation is occurring after historic incision and widening (left). New development on left bank in upper portion of segment has altered the stream planform (right).

Table 24. Beaver Meadow Brook (East Enosburgh) Reach T3.01 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T3.01A T3.01B T3.01C	Protect river corridor	Moderate High High	Low Moderate Moderate	N	B and C attenuation assets constrained upstream of Tyler Branch confluence; opportunities may grow with repeated conflicts
T3.01B T3.01C	Plant stream buffer	High High	Moderate High	Y	Primarily low cost; vertical and lateral instability
T3.01B	Stabilize stream bank	Moderate	Low	Y	Pond currently at risk due to stream bank erosion.
T3.01A T3.01C	Replace Existing Bridge Structures	Moderate Moderate	Moderate Moderate	Y	When bridge is due to be replaced consider structure that allows for more lateral movement of the stream.

6.1.17 Preliminary project identification: Reach T3S1.01 - Un-named tributary to Beaver Meadow Brook (East Enosburgh) from confluence to a point approximately due north of the intersection between Carpenter Road and Horseshoe Circle.

Reach T3S1.01, an unnamed tributary of Beaver Meadow Brook in East Enosburgh, is 2,748 feet long (0.52 miles) and was segmented once during the Phase 2 assessment process. Segments are 1,225 and 1,523 feet long. The reach has a Very Broad valley and soil maps show that hydric soils fill this valley for the entire reach length. During the Phase 1 process, this reach was classified as a C-type stream with a b-subslope (2-4%), riffle-pool bedform, and cobble substrate. Segment B retained this classification during the Phase 2 process. T3S1.01A, having been straightened and channelized, has experienced a stream type departure to an E-type stream with planebed bedform and gravel substrate. An unnamed tributary enters the reach roughly 400 feet downstream of the T3S1.02 reach break, and may be a historically diverted stream coming from Horseshoe Circle (see discussion in Sec. 5.1.1, Watershed hydrologic stressors, of this report). High recommendation is given for further assessment of this possible diversion, as stream dynamics downstream of here appear impacted by high flows.

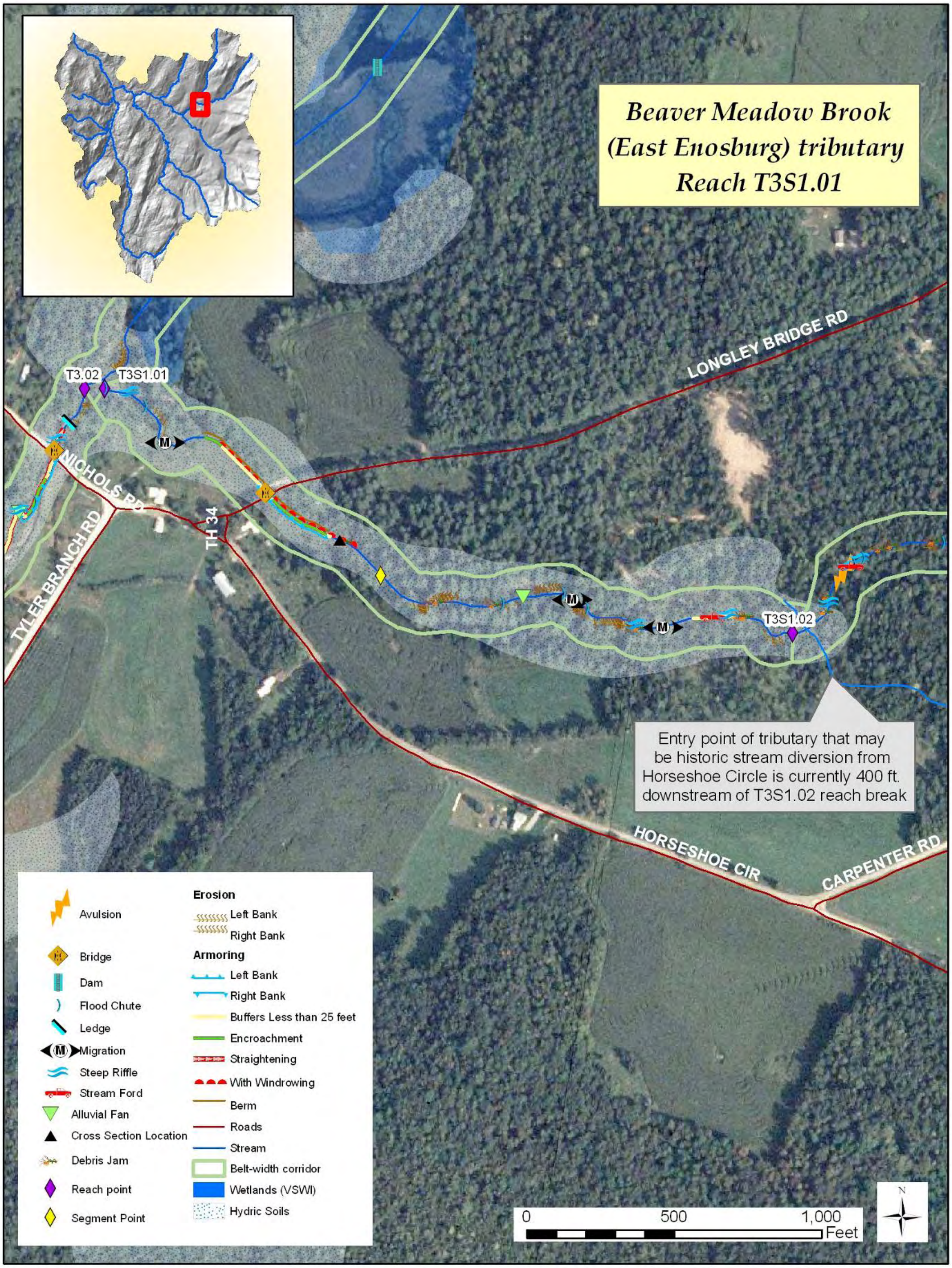


Figure 81: Un-named tributary to Beaver Meadow Brook (East Enosburgh), reach T3S1.01.

T3S1.01A (1,225 ft) is characterized by having been straightened, channelized and bermed along much of its left bank. The stream may have been dredged or bulldozed post flooding in 1997 or 1998 in an effort to clear sediments from the bridge at Longley Bridge Rd. Channel dimensions are narrower than would be expected for a C-type stream. Channelization may have both deepened the channel and lined the banks with material from the bed. There is some possibility that this section of stream could be an E-type by reference, but given the setting and slope, it seems more likely that it would naturally retain C-type channel dimensions similar to both upstream and downstream. Key features include:

- More than 50% of the segment appears to have been straightened and windrowed.
- There is a berm along the left bank for almost 40% of the segment (likely protecting downstream development).
- There is >20% armoring along the left bank of this segment.
- Buffer is <25 ft for almost 40% of the segment on the left bank.
- Longley Bridge Rd. bridge is sized at 108% of reference channel width but is showing signs of deposition upstream of the bridge.
- The stream is in stage II, with incision still the dominant process. Channel evolution maybe be somewhat inhibited by windrowing, armoring, and berming of the channel banks.
- Substrate is gravel, sensitivity rating is Very High, and geomorphic rating is Fair.

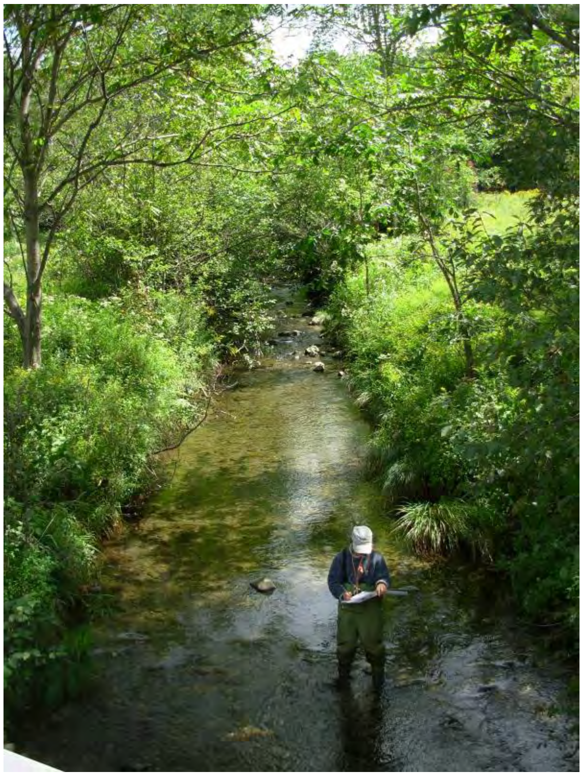


Figure 82: Reach T3S1.01, segment A shows significant historic straightening.

T3S.101B (1,523 ft) has been less manipulated and retains a more natural planform than segment A. Processes appear dynamic in this segment, as historic incision has led to widening and aggradation as the stream attempts to re-establish its equilibrium. Timber harvesting has taken place recently in the area, thinning the buffer, but not overly affecting the stream channel. There is one stream ford. Key features include:

- There are no corridor encroachments in this segment.
- Erosion is common with >20% effected on the left bank and >10% on the right bank.
- Debris jams are common, with 6 occurring in this segment.
- Buffers are >100 ft for the entire segment, on both sides.
- The stream is in stage III, historic incision having led to widening and aggradation. New floodplain benches are forming as the stream moves towards evolution stage IV (stabilizing).
- Substrate is gravel, sensitivity rating is High, and geomorphic rating is Fair.

Figure 83: Reach T3S1.01 segment B has a forested buffer. Widening following incision has led to a significant amount of bank erosion and tree-fall into the stream, causing debris jams.

Table 25. Un-named tributary to Beaver Meadow Brook (East Enosburgh) Reach T3S1.01 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T3S1.01A T3S1.01B	Protect river corridor	High High	Moderate High	N	Valuable attenuation assets. T3S1.01A currently constrained by development downstream of bridge; opportunities may increase with repeated conflicts
T3S1.01A	Plant buffers	High	High	Y	Mixed cost; flood mitigation, flow attenuation; more important if berm removal ever becomes feasible
T3S1.01A	Replace Existing Bridge Structures	Moderate	Moderate	Y	When bridge is due to be replaced consider structure that allows for more lateral movement of the stream.

6.1.18 Preliminary project identification: Reach T3S1.02- Un-named tributary to Beaver Meadow Brook (East Enosburgh) from point approximately due north of the intersection between Carpenter Road and Horseshoe Circle to downstream of Whitcombs Corner Road bridge.

Reach T3S1.02 is 5,899 feet long (1.12 miles) and was segmented four times during the Phase 2 assessment process. Segments are 2,499, 890, 914, and 1,595 feet long. This reach is characterized by a Broad valley and only a small amount of hydric soils in the valley, at the top of the reach. The Phase 1 process classified this reach as a C-type stream with a b-subslope (2-4%), a riffle-pool bedform, and a cobble substrate. Three of the 4 segments retained this classification. Segment B has experienced a stream type departure from C to F due to extensive historic incision.

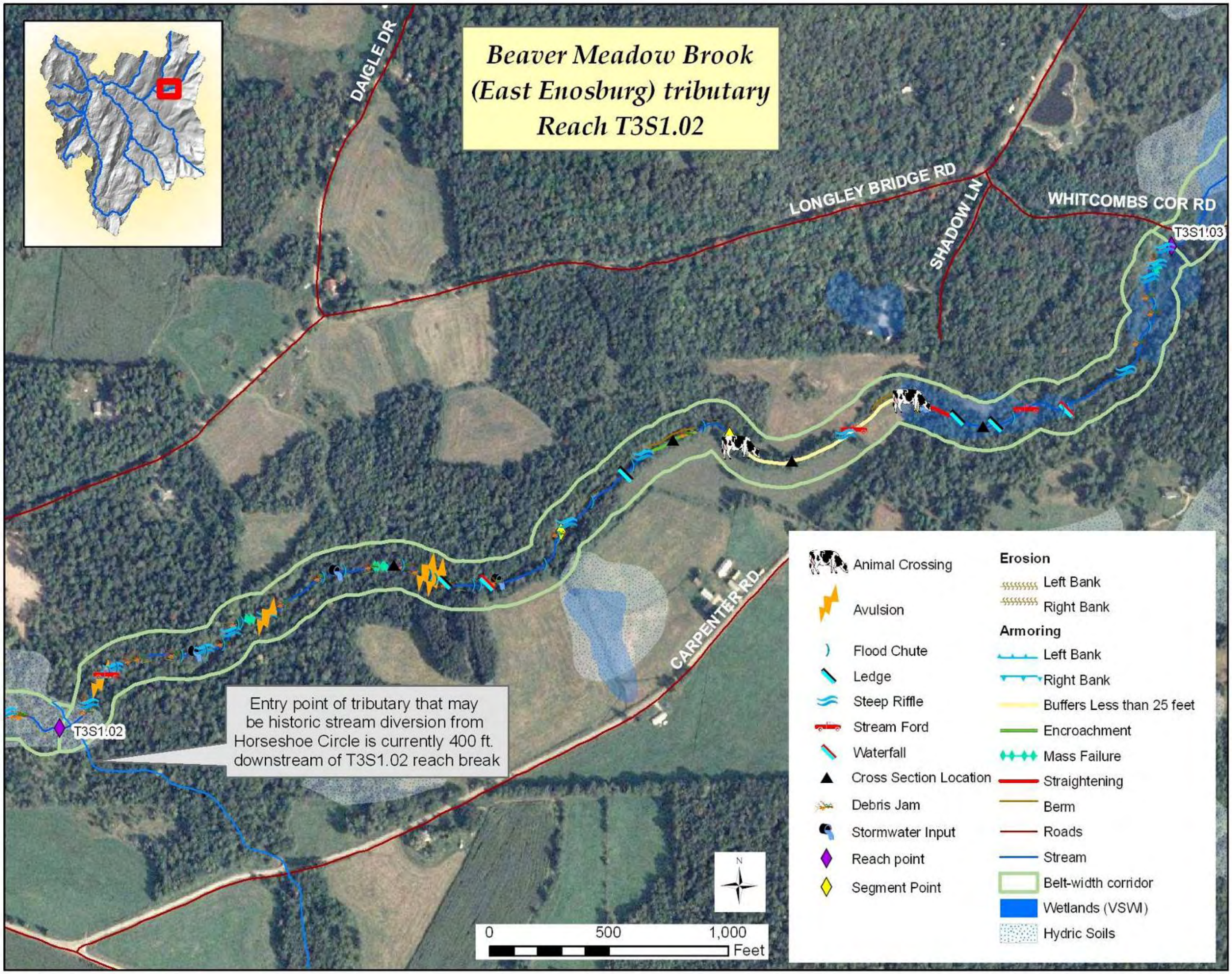


Figure 84: Un-named tributary to Beaver Meadow Brook (East Enosburgh), reach T3S1.02.

T3S1.02A (2,499 ft) is characterized by very dynamic processes. Evidence of major planform changes through avulsion is both historic and current. Bedrock grade controls inhibit incision. Key features include:

- There are no corridor encroachments for this segment.
- Dominant buffers are >100 ft for both sides.
- Mass failures and erosion are common in the segment.
- There were 4 channel avulsions and 16 flood chutes mapped for the segment.
- There were 6 mid channel bars and 6 steep riffles mapped for the segment.
- Debris jams are numerous due to eroding and sliding stream banks; 17 were mapped for this segment.
- Two grade control features are found in mid-segment. One measures 5 feet in height.
- The stream is in stage III. Incision is inhibited by coarse substrate and lateral movement is more common, although bed incision is possible in high flows. Widening and aggradation are dominant processes.
- Substrate is cobble, sensitivity rating is Very High, and geomorphic rating is Fair.


Figure 85: Reach T3S1.02, segment A shows significant aggradation (left). Mass failures and bank erosion in a forested setting has led to a significant number of debris jams (right).

T3S1.02B (890 ft) is characterized by having incised to the point in which it no longer accesses its historic floodplain and is entrenched to the point that it has experienced a stream type departure to an F-type stream. The valley confinement has also changed from broad to narrow. Key features include:

- There is no corridor development in this segment but agricultural pasture land is along the left bank.
- A berm stretches along 211 feet of the left bank, but appears to be related to rock-clearing for an agricultural field rather than to keep the stream from flooding
- Erosion is found on >20% of the right bank.
- This section of stream feels straightened but there is no direct evidence to support this.
- The stream is in stage III. Historic incision has led to widening and some aggradation.
- Substrate is cobble, sensitivity rating is Extreme, and geomorphic rating is Fair.

T3S1.02C (914 ft) is a short section of this reach that is part of an active pasture. Incision has occurred here but not to the extent that the stream has lost access to its broad valley. Key features include:

- Dominant buffer on both banks is 0-25 feet. Buffers are less than 25 ft on >50% of the right bank and >30% of the left bank.
- There is no corridor development in this segment but agricultural pasture land is found along both banks for the entire segment.
- Two stream fords were mapped. Cow crossings are also common.
- A berm stretches along 109 feet of the left bank, but appears to be related to rock-clearing for an agricultural field rather than as a stream flooding-inhibitor.
- Approximately 20% of this segment has been straightened.
- The stream is in stage III, with some areas still in stage II. Some areas are incised and do not appear to have started widening yet. Other areas have widened and are forming new floodplain benches.
- Substrate is cobble, sensitivity rating is High, and geomorphic rating is Fair.

Figure 86: Un-named tributary to Beaver Meadow Brook (East Enosburgh), reach T3S1.02 segment C. Agricultural pasture use has reduced buffers and caused some bank erosion in this segment.

T3S1.02D (1,595 ft) is a fairly stable section of stream with frequent bedrock grade controls, some wetland features, and a broad valley. Key features include:

- Dominant buffer on both banks is >100 feet.
- There is no corridor development in this segment and only a tiny bit of road encroachment at the top of the reach
- Three bedrock grade controls were mapped in this segment. One of them had a height of 6 feet.

- Aggradation in T3S1.02D is moderate, with 1 mid-channel bar, 13 side bars, and 4 steep riffles being mapped.
- Flood chutes are common in the segment (7 were mapped).
- The stream is in stage III. Historic incision has lowered the stream bed to where it has encountered bedrock. Further incision is unlikely. Widening and planform changes are somewhat inhibited by bedrock in the stream banks.
- Substrate is cobble, sensitivity rating is High, and geomorphic rating is Fair.

Figure 87: Reach T3S1.02 segment D has frequent bedrock in the bed and on the banks that inhibits incision, widening, and planform changes.

Table 26. Un-named tributary to Beaver Meadow Brook (East Enosburgh) Reach T3S1.02 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T3S1.02A T3S1.02B T3S1.02C T3S1.02D	Protect river corridor	High Moderate High Moderate	Moderate Moderate Moderate Moderate	N	Some attenuation available at the top of the reach. Some vulnerable stream banks in mid and lower reach.
T3S1.02C	Plant buffers	High	Moderate	Y	Stream banks destabilized by pasture use.

6.1.19 Preliminary project identification: Reach T4.01- Un-named tributary to the Tyler Branch mainstem from the confluence to just downstream of the Boston Post Road bridge.

Reach T4.01 is 1,789 feet long (0.34 miles) and was segmented once during the Phase 2 assessment process. Segments are 805 and 984 feet long. This reach was characterized during the Phase 1 process as having a semi-confined valley. Phase 2 assessment found only the upper portion of the reach having a semi-confined valley, with the lower widening into a very broad valley. The stream was classified as a B-type stream with a step-pool bedform and a cobble substrate. Segment B retained this classification, but segment A, due to a much broader valley and extensive manipulation of the channel, was found to be a C-type stream with a b-subslope (2-4%), planebed bedform and a gravel substrate.

Segment A (805 ft) is a highly manipulated section of stream in the middle of agricultural field and farmstead. Bedrock is found in the lower part. Key features include:

- Buffer vegetation is absent on both banks for almost the entire segment.
- There is >20% development on one side of the stream.
- Armoring is found on >30% of both banks.
- Almost 75% of the stream has been straightened.
- A farm bridge in mid-segment is sized at about 85% of reference bankfull width but has some deposition upstream, and a small footbridge is located in a heavily armored section downstream (Fig. 88)
- The stream is in stage IV. Historic incision in the upper protion of the segment has led to widening and new flood plain development. The downstream 300 ft of the segment is entirely armored and processes there are arrested.
- Substrate is cobble, sensitivity rating is Very High, and geomorphic rating is Fair.

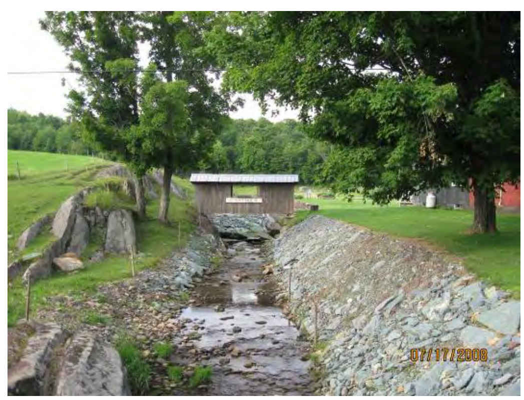


Figure 88: Reach T4.01, segment A has been straightened most of its length. The upper portion of the segment has created new floodplain (left), while the downstream end has been completely armored to prohibit lateral movement.

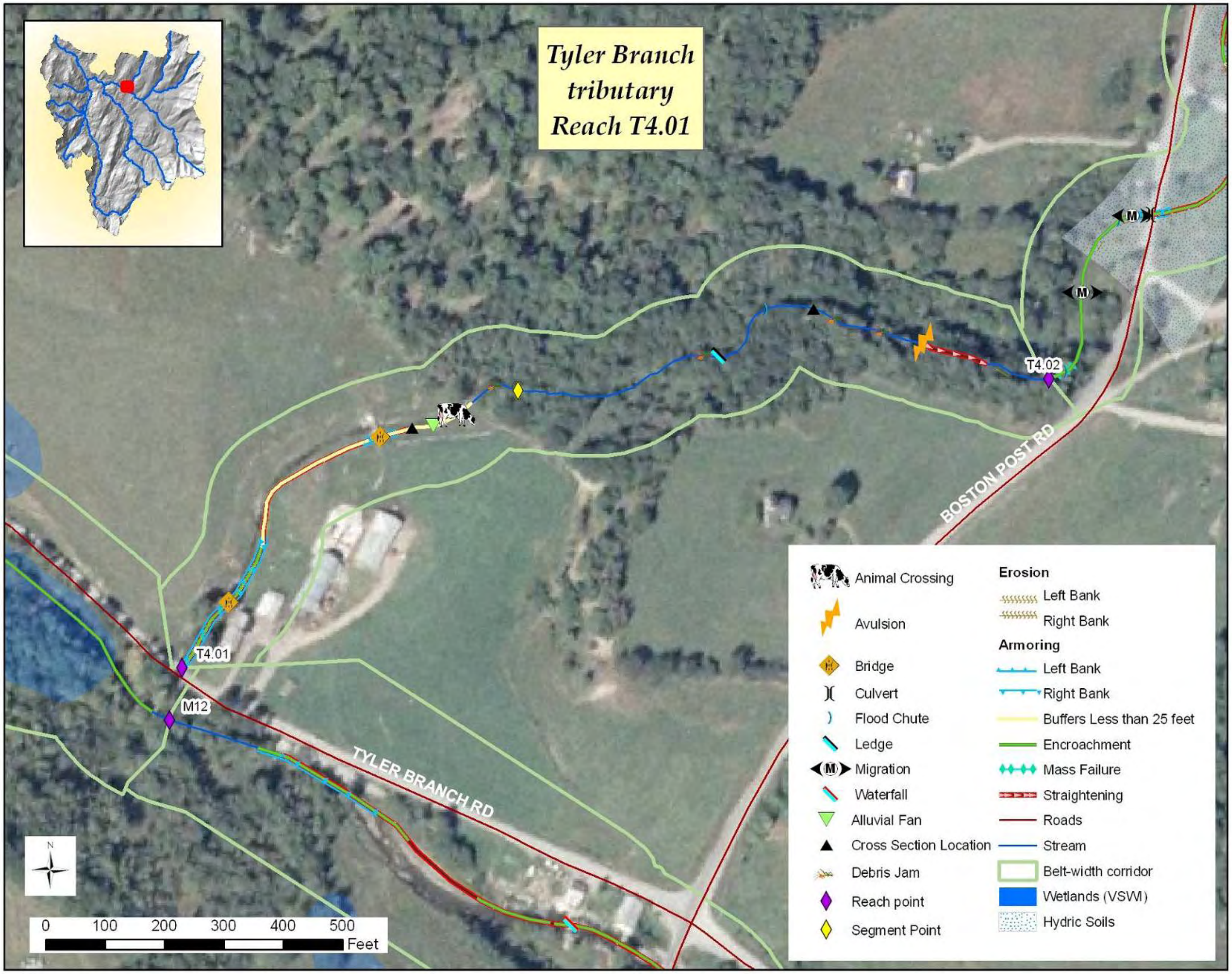


Figure 89: Un-named tributary to the Tyler Branch mainstem: Reach T4.01.

T4.01B (984 ft) has not been manipulated and is characterized by a forested buffer, a semi-confined valley, and a small amount of bedrock in the bed and banks. Key features include:

- Buffer vegetation is >100 feet on both banks.
- There is no development or encroachment on this segment.
- There is one bedrock grade control in mid-segment, with a total height of 4 ft.
- Aggradation is moderate, with 3 mid-channel bars and 7 side bars mapped.
- Moderate planform changes include an avulsion.
- The stream is in stage IV. Historic incision in the upper reach has led to widening and new flood plain development.
- Substrate is cobble, sensitivity rating is Moderate, and geomorphic rating is Good.

Figure 90: Reach T4.01 segment B is in relatively stable condition with coarse substrate and a forested buffer.

Table 27. Un-named tributary to Tyler Branch mainstem Reach T4.01 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T4.01A T4.01B	Protect river corridor	High High	Moderate Moderate	N	Attenuation available in the lower reach, above Tyler Branch Rd. crossing. Upper segment subject to bank failures.
T4.01A	Re-establish buffers, fencing	High	Moderate	Y	Stream banks somewhat destabilized by pasture use. Buffers would help moderate water temperatures.

6.1.20 Preliminary project identification: Reach T4.02 - Un-named tributary to the Tyler Branch mainstem, from just downstream of the Boston Post Road bridge to 4,454 feet upstream (less than half the way from the Boston Post Road bridge to the Nichols Road bridge).

Reach T4.02 is 4,454 feet long (0.84 miles). This reach is characterized by having a very broad valley, a C-type stream with a b-subslope, a riffle-pool bedform and a gravel substrate. Phase 2 stream and valley typing agreed with the Phase 1 assessment. This reach was not segmented. Agricultural use is heavy on almost the entire length of this reach. Soil maps show the entire valley to be dominated by hydric soils with the upstream portion of the reach also being classified as Class 2 NWI wetland. These features indicate that this reach has considerable attenuation assets. Key features include:

- Dominant buffer vegetation is 0-25 ft on both banks, with >50% of the right buffer and >30% of the left bank being <25 ft.
- There is a minimal amount of development, encroachment, and straightening on this reach.
- There are two town road culverts in the lower part of the reach. Both are significant constrictions.
- Aggradation is moderate to high, with 8 mid-channel bars, 9 side bars, and 5 steep riffles mapped.
- Moderate planform changes include 5 flood chutes and three avulsions.
- Cow crossings are frequent causing some bank erosion.
- The stream is in stage IV. Historic incision and widening in the reach is leading to aggradation and new floodplain development.
- Substrate is gravel, sensitivity rating is Very High, and geomorphic rating is Fair.

Figure 91: Reach T4.02. Two culverts in the lower part of the reach are significant channel constrictions (left). Extensive agricultural pasture use has caused reduced buffer and bank erosion (right).

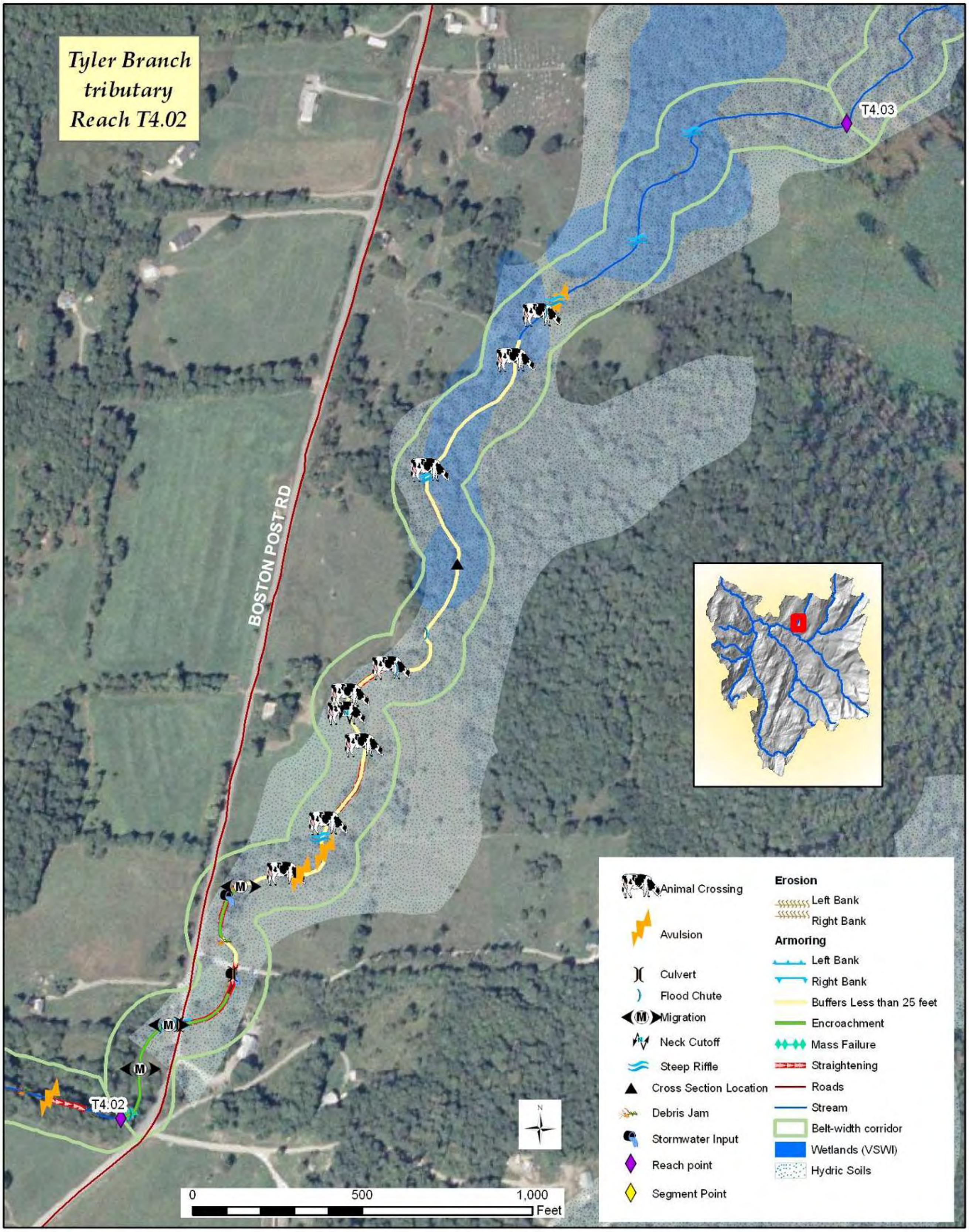


Figure 92: Un-named tributary to the Tyler Branch mainstem, reach T4.02.

Table 28. Un-named tributary to Tyler Branch mainstem Reach T4.02 Projects and Practices Table.

River Segment	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
T4.02 0	Protect river corridor	High	Moderate	N	Valuable attenuation asset upstream of road crossings.
T4.02 0	Re-establish buffers, fencing	High	Moderate	Y	Stream banks somewhat destabilized by pasture use. Buffers would help moderate water temperatures.
T4.02 0	Replace Existing Culvert Structures	High	Moderate	Y	Culverts are significant constrictions and should be replaced with correctly sized structures.

6.2 PROJECT PRIORITIZATION

The current hydrologic and sediment transport regimes in the Tyler Branch watershed place the highest priority, in terms of project prioritization, on two factors:

3) Reduction of stream power
4) Accommodation of planform adjustments, permitting both
    c) Full meander development; and
    d) Room for channel avulsions and rapid lateral migrations

Due to the particular importance of stream power in these dynamics in this watershed, the design and success of downstream restoration projects will be strongly affected by discharge and sediment loads higher in the watershed. Project prioritization thus emphasizes upstream restorations of equilibrium conditions whenever feasible, and when this is not feasible focuses on attenuation of impacts in the shortest possible distance downstream. The widespread distribution of the important stream assets needed for this restoration work makes parcel by parcel corridor protection efforts extremely challenging, and municipal governments can achieve many of the same goals much more efficiently and effectively. This is why the top priority recommendation in this report is for the Town of Enosburgh to consider belt-width corridors or similar measures for augmentation of current development review specifications, which are beneficial to the Town's water resources but could benefit from additional protection.

The Town of Bakersfield adopted 100 foot development setbacks from streams at their March 2009 Town meeting (http://nrpcvt.com/Zoning%20Bylaws/Bakersfield%20Zoning%20Bylaws.pdf, p.17). This width accommodates belt-width corridors on the large majority of streams in Bakersfield (belt-width corridors are based on over 30 years of research and data collected from hundreds of streams around the world, and approximate the extent of lateral adjustments likely to occur over time in a meandering stream type). The Tyler Branch mainstem in Enosburgh is a larger stream than those in Bakersfield, so 100 foot setbacks on that stream would not give the same level of flood protection and accommodation of stream processes that will help break the cycle of impacts being passed to downstream reaches. Smaller streams and areas of bedrock-controlled streams might not need as much of a setback. Fluvial Erosion Hazard zones (FEH) are recommended as a scientifically based method that uses the size, inherent sensitivity, and current adjustment processes of the stream to determine and map appropriate setbacks. Ways to develop these zones and models of various options for implementing them are explained in the Municipal Guide to Fluvial Erosion Hazard Mitigation published by the Vermont River Management Program (VT-RMP FEH 2008).

While these measures help limit development encroachments, it is also important to bear in mind that restriction of stream processes in undeveloped areas, particularly structural measures and other practices designed to maintain streams in a fixed location, will contribute to prolonged stages of disequilibrium and the erosion and lateral migration that streams will use to balance the energy of stream power and sediment loads. Bank armoring and bank toe stabilization are common at stream crossing structures and on undeveloped sites in the watershed, particularly along agricultural fields. Channel straightening is a challenging issue to address at a municipal level, and may need to be addressed more often at a localized scale. It has contributed significantly to the transfer of impacts to downstream reaches in the Tyler Branch watershed. Ample buffer establishment in straightened areas and downstream of them is important not only to bank and soil stabilization but also flood mitigation (diffusing stream power) and decreasing the rate and intensity of precipitation entering the stream. Low cost plantings and/or permitting natural regeneration are generally recommended in these areas due to the likelihood of lateral migration as streams evolve. There are a number of cost-share options for landowners wishing to establish buffers, including the Conservation Reserve Enhancement Program (within the Natural Resources Conservation Service).

The Introduction (Section 2.0) to this report includes an excerpt from the Missisquoi River Basin Association's internet homepage highlighting the phosphorus loading problems in Missisquoi Bay and Lake Champlain that have contributed to significant algae blooms. The origins of elevated phosphorus loads have been very difficult to identify, as the contributions of a number of intense storms in recent years, rates of water percolation, different soils, eroded banks, and similar issues appear to vary dramatically and present a complex dynamic with no easy answers. It is clear, however, that fully functional floodplains contribute enormously to storing these nutrients within the watershed, and heightened stream power – whether from natural events or stream modifications – has contributed to export of sediments and nutrients toward Missisquoi Bay and Lake Champlain, where these large bodies of water present a major decrease in stream velocity that drops out many of the finest sediments (carrying the largest proportion of nutrients and organics) being carried in streams.

Previous project identification (MRBA (Johnson) 2006) recommended reaches T1.08 – T1.11 on The Branch, along with further reaches upstream (unassessed at that time) likely as well, for a corridor protection plan due to a low level of residential development in the riparian corridor and numerous values to the watershed (habitat, sediment and nutrient retention, floodwater attenuation, fluvial adjustment capacity). Assessments in 2008 confirmed these values in reaches T1.13 and the lower end of T1.15 further upstream, as well as along reach T1S4.02 on Beaver Meadow Brook (along the County Rd.). The Town of Bakersfield went a long way to creating such a corridor protection plan with its March 2009 adoption of 100 foot setbacks for development. Impacts to stream dynamics that are not associated with development (including those from agriculture and forestry) are not addressed by setbacks and FEH zones, however.

A focus on upstream reaches is not meant to diminish project identification and prioritization based on 2005 Phase 2 assessments (MRBA (Johnson) 2006), but is meant to suggest that the fuller assessment of watershed dynamics made possible by additional assessments and analysis reported here indicate that the long-term success of downstream projects will greatly benefit from, if not depend on, remediation of upstream disequilibrium that currently exacerbates impacts in downstream reaches. With heightened stream power the most prominent issue in the watershed, bank and mass failure stabilization efforts will be at particular risk of being undermined (both figuratively and literally) by transfer of these impacts.

In addition, sediments will likely continue to accrue at areas of bar scalping and gravel mining, which create widened channels and a decrease in stream velocity in localized areas. At this point in the watershed's history, further bed degradation and active downcutting appears to be limited by a variety of factors, including numerous grade controls interspersed throughout the watershed. Headcuts appear to be "washing out" quickly with the recruitment of more sediment, but formation of planebeds and removal of these sediments: a) decreases the transfer of coarse sediments to downstream reaches, thereby limiting development of normal bed features (riffles and pools); b) increases transfer of stream power (heightening erosive power) and fine sediments; and c) inhibits meander development. The cumulative impact of these dynamics moving down the stream channel again increases the importance of prioritizing remediation of these issues upstream.

The large majority of reaches selected for inclusion in the Tyler Branch corridor planning area range from highly sensitive to very highly sensitive to changes in watershed inputs. Given these conditions, passive geomorphic restoration projects, which leverage these inputs and the river's own energy to facilitate a return to equilibrium conditions, are generally preferred for prioritization due to the likelihood of rapid stream evolution (this may be on a scale of decades for these streams to fully recover from a degraded state that is hard to recognize from a limited historical perspective). Lower investments associated with this approach are desirable considering an inherent degree of uncertainty in the success of engineered approaches in an active system, and the Tyler Branch watershed (particularly eastern portions) can certainly be characterized as an active, high-sediment-load system.

Stream sensitivity analysis indicates a concentration of very high sensitivity reaches in most of the eastern portions of this watershed. Due primarily to a) naturally high levels of precipitation along the mountains to the east and b) concentration of development in the villages of East Enosburgh, Gilbert’s Tannery, and West Enosburgh, as well as along Tyler Branch Road in general, there is a high degree of flood hazards in this portion of the watershed. The concentrated development and road encroachment in these areas has already restricted access to valuable floodplains and limited the amount of room available for meander development and lateral migration. The impairment of these attenuation assets increases the importance of protecting remaining assets in these areas as well as upstream and downstream, with the primary aim in downstream reaches being the protection of valuable floodplains to attenuate upstream discharges. Because discharges in this watershed include particularly high flows, and highly erodible materials are present along the banks of many downstream reaches, ample buffer establishment and maintenance is critical to permitting these functions without continuing to lose large amounts of fine sediments and valuable nutrients. Accommodation of floodplain access for streams, the valuable nutrients stored on these floodplains, and room for meander development makes these downstream reaches more appropriate for accommodation of stream processes and agricultural purposes than developed land uses.

With these considerations as a general backdrop, Table 28 lists potential prioritized projects with the greatest benefits in terms of restoring equilibrium conditions in the Tyler Branch watershed corridor planning area, in recommended order of priority. Project prioritization should be considered preliminary and will need to be adjusted based on further information and community interest.

Table 29. Potential project prioritization for the Tyler Branch watershed corridor planning project area

Tyler Branch watershed corridor planning Prioritized Project and Strategy Summary								
Project No.	*Reach/ Segment Condition Sensitivity*	*Site Description Including Stressors and Constraints*	*Project or Strategy Description*	*Technical Feasibility & Priority*	*Other Social Benefits*	*Costs*	*Land Use Conversion & Landowner Commitment*	*Potential Partner Commitments*
1	Tyler Branch mainstem M1-M15; The Branch T1.01-T1.06; Bogue Branch T2.01-T2.04; Tyler Branch tributaries T4, T3, T3S1; large majority High to Extreme sensitivity	Heightened stream power originating high in watershed; development and encroachment restricts necessary room for flood hazard avoidance and mitigation, full meander development, and channel migrations	FEH and belt-width-based corridor planning, protection of attenuation assets	Feasible, high priority; delineation process largely developed, model regulations and recom-mendations exist Upstream impacts strongly affect success of downstream projects	Flood hazard reduction, reduction of fine sediments (high in nutrients and organics) out of the watershed and toward Bay, prime farmland protection	Policy development and implementa-tion; Distribution of outreach and educational materials	Depends on options chosen; see VT-RMP Municipal Guide to Fluvial Erosion Hazard Mitigation (Literature Cited section of this report)	Town of Enosburgh; Northwest Regional Planning Commission; VT-RMP

Tyler Branch watershed corridor planning Prioritized Project and Strategy Summary								
Project No.	*Reach/ Segment Condition Sensitivity*	*Site Description Including Stressors and Constraints*	*Project or Strategy Description*	*Technical Feasibility & Priority*	*Other Social Benefits*	*Costs*	*Land Use Conversion & Landowner Commitment*	*Potential Partner Commitments*
2	T3S1.01A Fair Very High	Channelized stream; berm removal might impact existing development	Buffer planting	Feasible, high priority regardless of berm status – other social and stream benefits	Flood hazard mitigation (diffuse stream power), water quality and temperature	Planting stock	Open land to buffers; need sign-off from landowners	Missisquoi River Basin Association; CREP
3	T3S1.01B Fair High T3S1.02A Fair Very High	Attenuation at and upstream of Bluto Rd. tributary; flows need to be handled if wetland restoration not possible; large woody debris for attenuation best above tributary confluence; LWD may cause issues for bridge	Corridor protection; channel management rights or work to incorporate a)limitation of streamside cutting and b) leaving large woody debris (natural downfalls) in stream into forest management plan	Feasible, high priority	Flood hazard mitigation (trees provide structural diffusion of stream power); working forest conservation	Forest management plan revision; economic incentives to limit streamside cutting?	Amendments to forest management plan; limitation of streamside cutting	Landowner(s) and forester; County Forester, VT-ANR Forests, Parks and Rec, VT-DEC Water Quality foresters; VT Land Trust

Tyler Branch watershed corridor planning Prioritized Project and Strategy Summary								
Project No.	*Reach/ Segment Condition Sensitivity*	*Site Description Including Stressors and Constraints*	*Project or Strategy Description*	*Technical Feasibility & Priority*	*Other Social Benefits*	*Costs*	*Land Use Conversion & Landowner Commitment*	*Potential Partner Commitments*
4	T3S1.01A Fair Very High T3S1.01B Fair High	Heightened stream power, flood hazards (Tyler Branch Rd.), Transport reach downstream	Assess status of historic stream diversion, possibility of wetland attenuation for stream at Horseshoe Circle and Bluto Rd.	Feasibility currently unknown; high priority, affects downstream projects	Flood hazard reduction	Low cost for assessment; Culvert installation? (ideally sized 1.2x channel width); buffer estab-lishment	Town road; adjacent farm may impact farm fields	EQIP, CREP, Town of Enosburgh; VT-RMP
5	T2.04B Fair Very High	Bridge at Witchcat Rd. is a channel constriction further reduced by angle of alignment; possible structural fatigue needs further assessment	Assess bridge for possibility and need of replacement	Feasible but expensive; higher priority if unsafe; bridge located at bedrock and likely to outflank in flood (lowers priority for stream dynamics)	Public safety	VTrans database suggests $321,000 for replacement; adjustment of alignment might require land purchase	Relocation for better alignment might require land purchase from abutters	VTrans, landowners

Tyler Branch watershed corridor planning Prioritized Project and Strategy Summary								
Project No.	*Reach/ Segment Condition Sensitivity*	*Site Description Including Stressors and Constraints*	*Project or Strategy Description*	*Technical Feasibility & Priority*	*Other Social Benefits*	*Costs*	*Land Use Conversion & Landowner Commitment*	*Potential Partner Commitments*
6	M13 C	Potential gully forming, already significant stormwater input above Sand Hill Rd. bridge	Ditch remediation, reshaping, outlet to vegetated surfaces	Feasible, higher priority due to import-ance of heightened flow impacts in area	Road improve-ment, water quality, fish habitat	Significant regrading		Town of Enosburgh, Better Backroads
7	M13A M13 B Fair High (both)	Important attenuation asset upstream of Beaver Meadow Brook confluence; windrowing and snagging in M13B	Channel easement rights (higher priority on M13B) and/or forest management plan amendments	Feasible, but Camp-ground may actually be expanding sites to other side of stream as well; this would increase importance of corridor protection in M13A	Flood hazard mitigation; camp-ground	Purchase of easements, easement transactions; Forest management plan revision (if one exists); economic incentives to limit streamside cutting?	Limit streamside cutting, windrowing and snagging of channel; may impact current development plans	Brookside Campground and landowner(s) downstream; VT-RMP; VT River Conservancy or similar organization

Tyler Branch watershed corridor planning Prioritized Project and Strategy Summary								
Project No.	*Reach/ Segment Condition Sensitivity*	*Site Description Including Stressors and Constraints*	*Project or Strategy Description*	*Technical Feasibility & Priority*	*Other Social Benefits*	*Costs*	*Land Use Conversion & Landowner Commitment*	*Potential Partner Commitments*
8	T2S1.04C Poor Very High	Alluvial fan at Branon sugarhouse upstream channelized, not likely to be altered w/o repeated conflicts; valley side slopes above East Bakersfield Rd. bridge grazed, sliding; wetlands on Peaked Hill Rd. heavily grazed and recently gullied	Fencing (polywire currently fences paddocks across stream), buffer retention and augmentation, corridor protection and conservation of attenuation assets	Feasible, high priority heightened by upstream impacts and dynamics	Reduce sediment loading at East Bakersfield Rd. bridge, nutrient loading impacts on water quality	Fencing, watering system; buffer stock and planting; compensa-tion to remove cattle from wetlands	Fenced buffers, grazing exclusion from wetlands	CREP; EQIP; Partners for Fish and Wildlife

Tyler Branch watershed corridor planning Prioritized Project and Strategy Summary								
Project No.	*Reach/ Segment Condition Sensitivity*	*Site Description Including Stressors and Constraints*	*Project or Strategy Description*	*Technical Feasibility & Priority*	*Other Social Benefits*	*Costs*	*Land Use Conversion & Landowner Commitment*	*Potential Partner Commitments*
9	T2S1.04D Fair High	Sugarbush road system on shallow to bedrock soils; recent flash flooding initiated headcuts that could capture roads in stream network, eliminate valuable floodplain access, and damage roads	Arrest headcuts, augment buffers at these sites	Feasible, high priority	Guideline refinement for stream crossing would benefit forestry and sugaring, which currently lies between forestry and ag	Check dam installation, buffer augmenta-tion (could be natural regeneration)	Further assessment of road layout needed	Branon Family Maple Orchards, EQIP, VT-ANR Forests, Parks and Recreation, VT Agency of Agriculture, County Forester, Missisquoi River Basin Association

Tyler Branch watershed corridor planning Prioritized Project and Strategy Summary								
Project No.	*Reach/ Segment Condition Sensitivity*	*Site Description Including Stressors and Constraints*	*Project or Strategy Description*	*Technical Feasibility & Priority*	*Other Social Benefits*	*Costs*	*Land Use Conversion & Landowner Commitment*	*Potential Partner Commitments*
10	T2.03A Poor Very High T2.02C Fair Very High	Gravel removal contributing to sediment starving, prolonging disequilib-rium and passing of increased stream power downstream; intensive ag	Explore channel management easements in T2.03A; buffer establishment (and fencing) here and in T.202C downstream are important with this and could be done independently	Feasible; lower priority than upstream because somewhat dependent on changes in flow and sediment loads there; buffers high priority	Flood hazard reduction, fish habitat and passage benefits	Purchase of easements, easement transactions; buffer stock and planting; economic incentives for sourcing gravel?	Gravel supply stockpiled for farm use, may need other source; hay/ pasture to buffers	CREP; EQIP; Partners for Fish and Wildlife; VT-RMP; VT River Conservancy or similar organization
11	T2.01C Fair Very High	Large mass failure beneath Bogue Rd. somewhat stabilized; straightening increases pressure on valley wall in floods	Feasibility and cost benefit analysis of possible road relocation; future floods may destabilize bank further	Unknown feasibility; high priority for road, lower priority for stream; sediment not reaching stream now	Could be reduced road repairs over time	Unknown	Might require extension of town ROW to get road far enough back from eroding valley wall	Town of Enosburgh, Better Backroads

Tyler Branch watershed corridor planning Prioritized Project and Strategy Summary								
Project No.	*Reach/ Segment Condition Sensitivity*	*Site Description Including Stressors and Constraints*	*Project or Strategy Description*	*Technical Feasibility & Priority*	*Other Social Benefits*	*Costs*	*Land Use Conversion & Landowner Commitment*	*Potential Partner Commitments*
12	M14A Fair High	Headcut at top of recently formed gully may undercut Wright Farm farm road	Arrest headcut, augment buffers (not actually a stream most of the time)	Feasible; lower priority for stream dynamics but high priority for landowner	Farm infra-structure, water quality	Installation of check dam or other grade control, buffer stock and planting	Hay land to buffers, help with or permission for installation of grade control	Wright Farm, CREP, EQIP, Missisquoi River Basin Association

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Tyler Branch Phase 2 Stream Geomorphic Assessment 2008-2009
Appendices

Appendix 1. Rapid Geomorphic Assessment (RGA) and Stream Geometry Summary Reports

Appendix 2. Phase 1 Reach Summary Reports

Appendix 3. Phase 2 Reach/Segment Summary Reports

Appendix 4. Plots of Channel Cross Sections

Appendix 5. Quality Assurance/Quality Control (QA/QC) Reports

Appendix 6. Consolidated Project Identification Table (from Chapter 6.1 Preliminary Project Identification)

Appendix 7. Large Format (11x17 in.) Maps

Appendix 8. Bridge and Culvert Summary Reports